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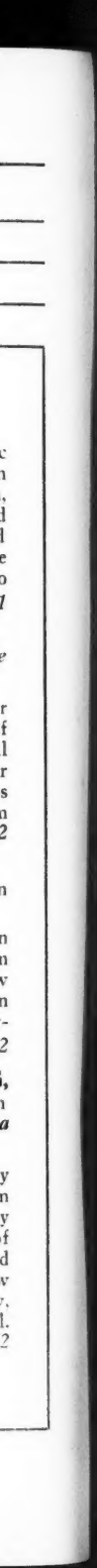

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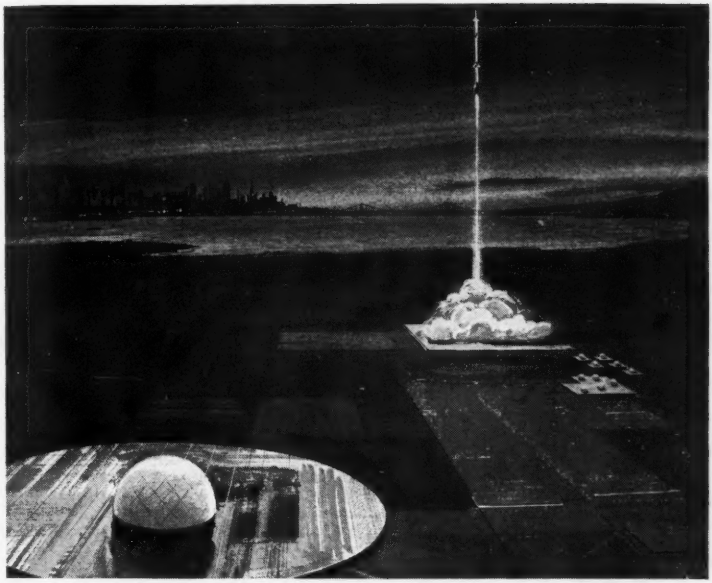

More than 450,000 pounds of thrust lifts the U. S. Army's Nike Zeus missile skyward in a cloud of vapor. The Nike Zeus missile being developed for the project by the Douglas Aircraft Company will be designed to intercept ballistic missiles traveling over 15,000 miles per hour, and destroy them at a safe distance from the defended area.

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Do You Know

● That apologies are extended to all for the short time permitted for the return of suggestions for the nominees for officers and the return of the Yearbook data card? The transfer from one printer to another went smoothly and without major mishap except for the preparation of the new addressograph plates. There, one thing after another happened and the plates were not available for mailing as early as had been planned. We still want your correct address, title, and divisional affiliations, so if anything in last year's Yearbook—Directory is incorrect, please send us the changes immediately.

● That the theme for the recent ECPD annual meeting was "Where Does Professional Specialization Belong in the Engineering Curricula?" LeVan Griffis spoke on the "Problems of the Undergraduate Curricula," L. E. Grinter on the "Problems of the Graduate Curricula," William Selden on "The Problems of Accreditation," and Lloyd Elkins spoke on "Effects on Industry." The newly-elected officers are R. A. Morgen, president; W. Scott Hill, vice president; E. O. Kirkendall, secretary. Miss Elsie Murray continues as executive secretary. The committee chairmen are: Guidance—D. M. Seeley; Student Development—J. S. Johnson; Education and Accreditation—N. A. Hall; Development of Young Engineers—John Gammell; Recognition—Guy Savard; Ethics—E. K. Nicholson; and Information—F. W. Starratt.

● That the Pacific Southwest Section is holding its annual meeting at the Stardust Hotel in Las Vegas on December 27 and 28? It is rumored that there will be a program, too.

● That the ASEE-AEC Summer Institutes on Nuclear Engineering for 1962 have been announced? The new eight-week Orientation Institute for teachers wishing to introduce nuclear aspects into courses they are now teaching and who do not expect to specialize in teaching nuclear engineering subjects will be offered at Iowa State and North Carolina State. Reactor Kinetics, two entirely different courses, will be offered at Penn State and at the University of Illinois, the latter is an eight-week course while the former is for six weeks. Four-week specialized institutes on reactor theory will be offered at North Carolina State, on reactor laboratory at the University of Florida, and on materials for nuclear reactors by the University of Washington at the Hanford Works, Richland, Washington.

● That the following are excerpts of the representatives of ASEE on the Council of the American Association for the Advancement of Science? At last year's meeting Section M (engineering) continued its consideration of national and international aspects of systems and units which it called "Operations SCUDS," meaning simplification, clarification, unification, decimalization, and standardization. The representatives of ASEE record, with concern, that engineering in the American Association for the Advancement of Science has deteriorated. It is their earnest desire to reverse the downward trend, which is reflected in the declining number of engineering members in the association. In February 1958, Section M membership was 4,077, or 7.5 per cent of the gross AAAS membership of 54,421. In addition, 1,926 members chose engineering as their secondary interest. In 1959, Section M's membership dropped to 3,715, and on June 1, 1960, it was only 3,413, or 6.2 per cent of a membership totaling 55,095. The drop in engineering interest followed closely upon the AAAS

council's ill-considered decision to discontinue publication of *The Scientific Monthly*. The officers and Board of Directors of AAAS have not done much to encourage greater engineering participation in association activities. Engineering is not represented on the board, but there are two engineers in the vice presidencies. Members of the engineering profession have it within their power to alter the situation and even change—or at least affect—the complexion of AAAS activities and engineering interests. A strong program with a public relations motive could be arranged, appropriately by EJC, and the authors of significant papers could load the pages of *Science* with articles of engineering interest, not only to members of the profession, but also to the 60,000 readers of this weekly journal.

• That during the past decade, the western and north central states have expanded their higher education systems more rapidly than the south and northeast? The rising proportion of children attending college has replaced population growth as the most dynamic factor influencing enrollment in higher education. Between 1950 and 1960, the total college enrollment jumped from 2.3 to 3.6 million. Yet the college-age population (18 through 24 years old) actually dropped from 15.8 to 15.6 million. Nationally, the number of students seeking degrees rose from 14.6 to 23.1 per cent of the college-age group. In 1960 California had 38 persons seeking college degrees for every 100 youngsters in the 18 through 24 age bracket, leads all the major states in providing college education for its youngsters and has the highest total enrollment of any state. In contrast, New York has about 27 students for every 100 people age 18 through 24. It ranks second nationally in total college enrollment, but has slipped from the fourth to the fourteenth place in the ratio of students to its college-age population during the past ten years. The District of Columbia, South Dakota, Nebraska, California, Oregon, Wyoming, North Dakota, Utah, Arizona, and Massachusetts show the greatest percentage gains. These data come from "College Enrollment Potential in Michigan, 1960-1975;" the author is David Goldberg, and copies may be obtained for one dollar each from the Institute for Public Administration, University of Michigan, Ann Arbor, Michigan.

• That this sounds like an up-to-date list of problems in engineering education?

Engineering Students at the Time of Entrance to College
Admissions and Eliminations of Engineering Students
Engineering Graduates and Non-Graduate Former Students
Engineering Teaching Personnel
Supplementary Activities of Engineering Colleges
Costs of Engineering Education
Engineering Degrees
A Study of a Group of Electrical Engineering Graduates
A Summary of Opinions Concerning Engineering Curricula
A Study of Engineering Curricula
A Study of Evolutionary Trends in Engineering Curricula
A Study of the Cooperative Method of Engineering Education
Opinions of Professional Engineers Concerning Educational Policies and Practices
The Summer School for Engineering Teachers
A Study of Placement Examinations
A Comparative Study of Engineering Education in the United States and in Europe

These are the titles of bulletins, 1 through 16, respectively, published by ASEE (SPEE) under the general heading of "Bulletins of the Investigation of Engineering." All were published prior to 1931 because they are listed in the January, 1931, issue of the JOURNAL OF ENGINEERING EDUCATION as publications of the Society. If anyone has copies of these bulletins or of any of the 13 "Bulletins of the Summer School for Engineering Teachers," please send them to the Secretary for the permanent records of the Society.

• That the *Periodical Monitor* is a new

magazine, providing engineers immediate reference to hundreds of articles on electronics and instrumentation each month? It features abstracts of the articles and is cross-referenced, with every abstract listed under every possible subject heading. There is no advertising content. For subscription information write to The Periodical Monitor and Abstract Service, 15 North Euclid Avenue, Pasadena, California.

● That the National Science Foundation's first grants under its institutional grants program totaled nearly $1,500,000 going to 248 colleges and universities? The amount of each grant was five per cent of the amount of NSF basic research grant payments made to the institutions during the period of July 1, 1960, through March 31, 1961, with a maximum payment of $37,500. The purpose of the grants is to strengthen the overall scientific research and research-training effort by providing flexibility for strengthening and balancing scientific research activities without specifying the particular activities to be undertaken with the funds. The use of the funds is to be reported to NSF annually.

● That 263 National Science Foundation graduate fellowships went to engineers for the academic year 1961-62? There were 4,875 applicants from all parts of the U. S. and its territories. A total of 1,537 fellowships were awarded in science, mathematics, and engineering; 347 awards were in the life sciences, 34 in certain areas of the social sciences, and 893 in the physical sciences, exclusive of engineering. The purpose of the program is to encourage outstanding college graduates to obtain advanced training in the sciences and engineering on a full-time basis.

● That copies of the *Proceedings of the Advisory Conference on Mechanical Engineering Experimental Laboratory Curricula* are now available? The results of this 1960 conference were published by the Engineering Experiment Station of Ohio State University as "Special Report 20." As long as they last, copies may be obtained by writing to the Engineering Experiment Station, 156 West 19th Avenue, Columbus, Ohio. This public service on the part of Ohio State and its Experiment Station is sincerely appreciated.

● That the U. S. Office of Education has completed negotiations of 123 contracts totaling $8.4 million for research and studies on how to improve teaching of modern foreign languages? The money became available under Title VI of the National Defense Act for 1958 and has been allocated for the three years, 1959, 1960, and 1961. Eighty-three languages and dialects are involved. It is estimated that this program will accomplish in four years what would normally have taken half a century. Every geographical area in the world is represented in the program, but emphasis is given to the Near and Middle East, the Far East, South and Southeast Asia. The 12 projects in the African languages is limited because only about a dozen scholars are competent to work on the languages. Proficiency tests for teachers are being developed by the Educational Testing Service. The new instructional programs being developed in the commonly taught languages will lead to the expansion of the customary high school two-year language program to a complete sequence of language training for grades 7 through 12. Physics, chemistry, the biological sciences, and now the languages have received their millions and the results have been judged to be very beneficial. There is no doubt but what the graduates of secondary school will be much better prepared in the future. This means that the colleges and universities must be sure that they will be adapting their programs to the "new" students. Engineering cannot afford to overlook the preparation of the high school graduate and must readjust its programs to the quality of incoming students. It now is time for engineering education to get its millions of dollars and develop appropriate programs before we learn by the hard way that our curricula and course content haven't kept up with the capabilities of the incoming students.

W. Leighton Collins
Secretary, ASEE

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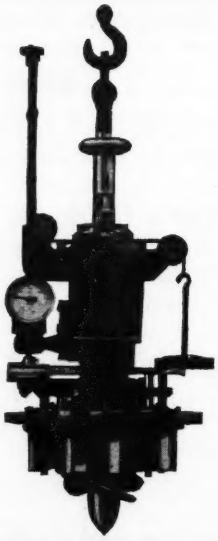

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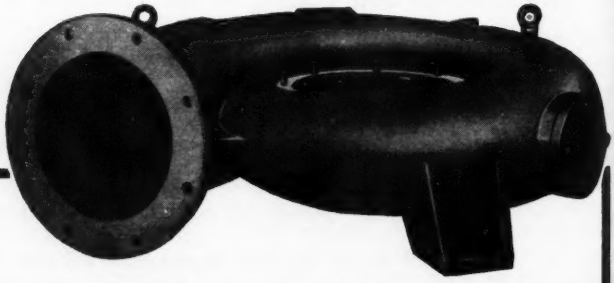

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Announcement of Awards

Nomination forms for the awards listed below and a convenient form for summarizing information may be obtained from the Committee Chairman or from the Secretary of the Society, W. Leighton Collins, University of Illinois, Urbana, Illinois.

Lamme Award

The Lamme Award consists of a gold medal and bronze replica bestowed annually upon a distinguished engineering educator for excellence in teaching and contributions to research and technical literature; achievements which contribute to the advancement of the profession, and engineering college administration. The Lamme trust fund was established in memory of Benjamin Garver Lamme in 1928.

Preliminary nominations should be submitted by letter to the Chairman of the Lamme Award Committee, M. R. Lohmann, Dean of Engineering, Oklahoma State University, Stillwater, Oklahoma, on or before January 1, 1962. Additional information should be mailed by February 1, 1962.

Vincent Bendix Award

This gold medal and citation are presented for outstanding research contributions, either in original thought or administrative leadership, to a staff member of an engineering college in the United States. The Award was established through the efforts of the ECRC and the Bendix Aviation Corporation.

Preliminary nominations should be submitted on or before January 1, 1962, to J. R. Ragazzini, Dean of Engineering, New York University, University Heights, New York 53, N. Y. Additional information should be submitted by February 1, 1962.

Curtis W. McGraw Research Award

Primarily intended to recognize an outstanding young member of an engineering college research staff in the United States, the Award is limited to nominees who will be under 40 years of age on June 30, 1962. This prize, sponsored by ECRC with the assistance of the McGraw-Hill Book Company, consists of $1,000 in cash and an engraved certificate.

Preliminary nominations should be submitted to C. M. Sliepcevich, Chemical Engineering Department, University of Oklahoma, Norman, Oklahoma, by January 1, 1962. Additional information should be submitted by February 1, 1962.

George Westinghouse Award

This award was established by the Westinghouse Educational Foundation as an annual award to young engineering teachers of outstanding ability to recognize and encourage their contributions to the improvement of teaching methods for engineering students. It consists of $1,000 in cash and an engraved certificate. Nominations should be sent to the Chairman of the Committee, E. R. Whitehead, Director, Department of Electrical Engineering, Illinois Institute of Technology, Chicago 16, Ill., by March 1, 1962, and they must be accompanied by documentary evidence supporting major statements and claims.

James H. McGraw Award

Each year the Technical Institute Division presents to an outstanding contributor to Technical Institute education this award. Established by the McGraw-Hill Book Company, the award consists of $500 and an engraved certificate. Nominations are to be submitted to the Chairman of the James H. McGraw Award Committee, H. E. McCallick, Capitol Radio Engineering Institute, Washington, D. C., by March 1, 1962.

Man is like a Goldfish in a Bowl of Ink

[redacted]

Man's view of the "ultraviolet universe" is shut off by the blanket of air which surrounds him.

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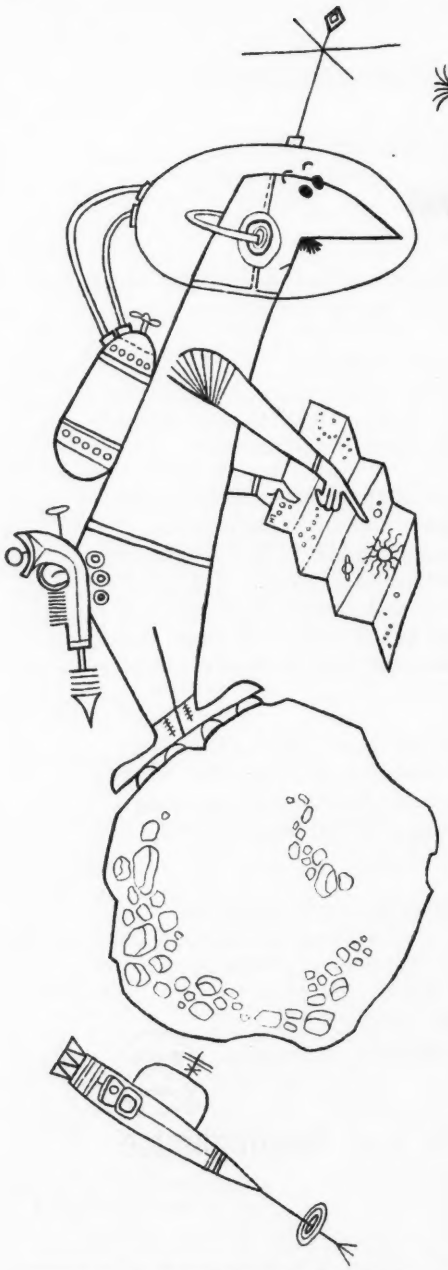

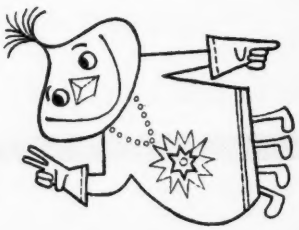

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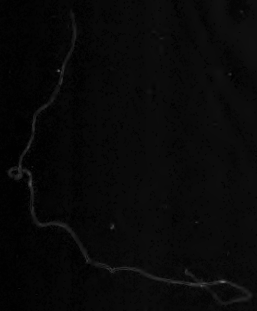

OFFICERS NOMINATED FOR 1962-63

The Nominating Committee met in Kansas City on Friday, November 17, and selected the following candidates:

For **President,** one year . . . . . Glenn Murphy

Professor and Head of Theoretical and Applied Mechanics, Iowa State University; member, General Council, 1946-47, 1953-55; Vice President, 1957-59; member, Nuclear Committee, 1957- ; Chairman, Study of Objective Criteria for Nuclear Engineering Education, 1960- ; member of ASEE since 1929.

For **Vice President,** Instructional Division, two years . . . . . George A. Hawkins

Dean of Engineering and Director, Engineering Experiment Station, Purdue University; member, Committee on Recognition and Incentives for Good Teaching, 1952-53; member, Atomic Energy Education Committee, 1952-54; member, Committee for Evaluation of Engineering Education, 1952-55; member, Annual Meeting Committee, 1959- ; Chairman, Advisory Committee for the 1960 Annual Meeting; member of ASEE since 1930.

For **Vice President,** Sections West of the Mississippi River . . . . . Archie Higdon

Professor and Head of Mechanics, United States Air Force Academy; member, Mechanics Division Executive Committee, 1957-60; Vice Chairman, Rocky Mountain Section, 1958-59; Chairman, Rocky Mountain Section, 1959-60; Chairman, Mechanics Division, 1959-60; Chairman, Local Committee for the 1962 Annual Meeting; member of ASEE since 1938.

For **Treasurer,** one year . . . . . George D. Lobingier

Director, Educational Department, Westinghouse Electric Corporation; member, General Council, 1953-55; member, ECAC Manpower Committee, 1957-60; member, Nuclear Committee, 1958-59; member, Industrial Membership Committee, 1958-59; member, George Westinghouse Award Committee, 1958- ; Chairman, Financial Policy Committee, 1960- ; member of ASEE since 1945.

ADDITIONAL NOMINATIONS

In accordance with the revisions of the constitution and bylaws adopted in June of 1957, *additional nominations may be made by petition* of fifty (50) signatures of members of the Society in good standing. The nominee must indicate a willingness to serve, if elected, before his name can be placed on the ballot. Petitions are to be submitted to the Secretary of the Society by January 15, 1962.

Ballots with the names of all candidates will be mailed to the membership by February 15. Ballots received by the Secretary by March 31 shall determine the election of the officers as of April 1. Their terms of office shall begin ten days after the date of the Annual Meeting.

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Fostering Creativity in Students of Engineering

DONALD W. MacKINNON

Director, Institute of Personality Assessment and Research, University of California, Berkeley

We have no certain knowledge as to how to foster more effectively the potential creativity of engineering students. This is not to say, however, that we know nothing about the creative process and creative persons. Recent investigations, like those in the Institute of Personality Assessment and Research on the Berkeley campus of the University of California, have shed considerable light upon the nature of creativity and the distinguishing characteristics of highly creative persons. But to make inferences from these findings as to how to identify creative potential in engineering students and how best to develop their creativity, is a precarious undertaking.

The difficulties are several. Most of the subjects in our investigations have been mature persons in a number of fields of creative endeavor: engineering and scientific research in industry, mathematics, architecture, writing, etc. Whether or not or to what extent we can generalize from our findings with mature, creative, productive individuals to students in schools and colleges of engineering, I do not know.

A talk given to the Faculty Seminar, School of Engineering, Stanford University, California, November 30, 1960. The findings reported here are from a larger investigation of creative work and creative workers in the arts, sciences, and professions being carried out in the Institute of Personality Assessment and Research supported in part by funds granted by the Carnegie Corporation of New York. The statements made and views expressed here are, however, solely the responsibility of the author.

Although our subjects have told us about their early years and especially their experiences in school and college, we must remind ourselves that, first, these are self-reports subject to the misperceptions and self-deceptions of all self-reports, and, second, the conditions in colleges and in society which would appear to have contributed to creative development 15 to 30 years ago might fail to facilitate creativity or might even inhibit it in today's vastly different world. Furthermore, we do not know that the traits which distinguish our creative workers as adults characterized them when they were students.

We have also studied students: candidates for the Ph.D. in some 14 fields of study, senior women in a college of liberal arts, and graduating seniors, mostly honor students, in the College of Engineering on the Berkeley campus of the University of California. But when we find in these students, as we have in some, the same patterns of traits which characterize our mature, creative persons, we cannot be certain that we have identified those who will be living productive, creative lives 15 to 30 years from now. Until future follow-up studies of our student subjects are made, any predictions as to which of them will be creative in their professional careers are not yet confirmed.

In view of all these warnings, how can I venture any suggestions as to how you may more effectively identify and develop creativity in your students? The most I can do is the following: First, I shall assume (but note that this is only a questionable assumption) that the interests, values, attitudes, cognitive styles, and

personality patterns of mature creative workers are congruent with or foreshadowed by the interests, values, attitudes, cognitive styles, and personality patterns of students who have creative potential or are already manifesting creativity. Second, I shall do no more than make the best guesses I can as to what conditions in colleges and in society and more specifically in your instruction will tend to maximize and bring to realization the potential of students for creative thought and action.

What Is Creativity?

Since creativity has been so variously defined, I feel some obligation to indicate the sense in which I use the term. True creativity, I would argue, must fulfill at least three conditions. It involves a response that is novel or at least statistically infrequent. But novelty or originality of behavior, while a necessary aspect of creativity, is not sufficient. If a response is to lay claim to being a part of the creative process, it must to some extent be adaptive to reality. It must serve to solve a problem, fit a situation, or in some sense correlate with reality. And, thirdly, true creativity involves an evaluation and elaboration of the original insight, a sustaining and developing of it to the full.

What I am suggesting is that creativity is a process which has a time dimension, and which involves originality, adaptiveness, and realization. It may be brief, as in the jam session of a jazz band, or it may involve a considerable span of years, as was required for Einstein's creation of the theory of relativity.

Phases of Creativity

There are distinguishable stages or phases of creativity: (1) a period of preparation during which one acquires the skills, techniques and elements of experience which make it possible for one to pose a problem to oneself, (2) a period of concentrated effort to solve the problem, which may be suddenly solved without much delay or difficulty, but which perhaps more often involves so much frustration and tension and discomfort that out of sheer self-protection one is led to (3) a period of withdrawal from the problem, a psychological going-out-of-the-field, a period of renunciation of the problem or recession from it, (4) a period of insight, a sudden cognitive reorganization of the problem accompanied by the exhilaration, glow and elation of the "aha" experience, and (5) a period of verification, evaluation and elaboration of the insight which one has experienced.

The process has been well described by Bertrand Russell, who has written that, "In all creative work that I have done, what has come first is a problem, a puzzle involving discomfort. Then comes concentrated voluntary application entailing great effort. After this a period without conscious thought, and finally a solution bringing with it the complete plan of a book. This last stage is usually sudden, and seems to be the important moment for subsequent achievement" (Hutchinson, 1949, p. 112).

For most persons, however, the process of creativity is not so easily come by as it apparently is for Bertrand Russell, nor are all of its phases easy to endure. We should perhaps, then, be prepared to discover that those who have high creative potential as well as those who have demonstrated true creativity will show a disposition to undertake problems where the degree of difficulty and frustration is great, and the drive toward completion or accomplishment is persistently strong.

The Assessment Method

The data which I shall report to you, and whose implications I shall discuss, have been gathered in a series of investigations of creative work and creative workers in the arts, sciences, and professions. In this research we employ what has come to be known as the assessment method, the distinctive method of psychological research which was developed in the Office of Strategic Services during World War II for the purpose of studying the functioning of highly effective individuals. Its essential feature is that the persons to be studied are brought together for several days at an assessment

center, where they meet with each other and with staff members, and participate in a series of experiments, psychological tests, and interviews covering the life history and professional career.

The assessed groups with whom I shall be most concerned in this report are the research scientists working in industry and the senior engineering students mentioned earlier.

The sample of research scientists consisted of 45 males employed in three industrial organizations which are engaged in research and development in the fields of guided missiles and electronics.[1]

The 45 subjects ranged in age from 24 to 54 with a mean age of 35 years. All but one are married. Twelve were foreign born. All but five of the group have had some formal graduate training; and 28 of them have earned the doctorate in their specialties. Seventeen had been trained as engineers, 22 as scientists (mostly in physics), five in mathematics, and one defies classification. Each research scientist was rated by two supervisors and peers on the "creative originality" which he had shown in his work.

These data permit two breakdowns of the sample: (1) 17 engineers *vs.* 27 non-engineers (physical scientists and mathematicians), and (2) 15 industrial researchers with highest mean ratings on creative originality *vs.* 15 industrial researchers with lowest mean ratings on creative originality; these latter will be referred to as Highs and Lows on creative originality.

The sample of engineering students consisted of 40 male seniors, mostly honor students, who were willing to be studied.[2] Each assessed student was rated by faculty members on a number of criterion variables, the most important for our present discussion being the rating of "originality potential."

Two other assessed samples, data from which will be referred to when relevant, are a nation-wide sample of 40 architects nominated by architectural experts as highly creative, and a comparison sample of 41 architects, matching the creatives with respect to age and geographic location of practice but not recognized by experts as being especially creative.[3] The relevance of these samples to our discussion lies in the fact that architects usually have some training in engineering as well as in art and have to have skill and competence in both, as well as in architecture.

Patterns of the Creative

The first finding to which I would call your attention is one which we made in our first study of graduate students. This finding (Gough, 1953), repeatedly confirmed in subsequent studies of other groups, is that those individuals who are rated high on originality or score high on a composite measure of originality (Barron, 1955) reveal a characteristic pattern of scores on certain scales of the *Strong Vocational Interest Blank* (Strong, 1959). From sample to sample there has been some slight variation, but the general pattern is this: the more original subjects show relatively higher scores on such scales as psychologist, architect, author-journalist, and specialization level, and relatively lower scores on scales such as purchasing agent, office man, banker, farmer, carpenter, veterinarian, and understandably enough, policeman and mortician.

This pattern of relatively high and relatively low scores on the *Strong Vocational Interest Blank* suggests that the

[1] This study of professional research scientists was conducted by Dr. Harrison G. Gough and Mr. Donald G. Woodworth. I am indebted to them for the findings here presented. For an over-all report on their research see the forthcoming monograph, H. G. Gough and D. G. Woodworth, *Personality Patterns Among Research Scientists* (in preparation), and the articles already published by them listed in the references for the present paper. The firms in which the industrial researchers worked were the Dalmo-Victor Company, San Carlos, California; the Lockheed Corporation Laboratories, Sunnyvale, California; and Varian Associates, Stanford, California.

[2] The assessment of student engineers was also conducted by Dr. Harrison G. Gough and Mr. Donald G. Woodworth, who have made the findings here presented available to me.

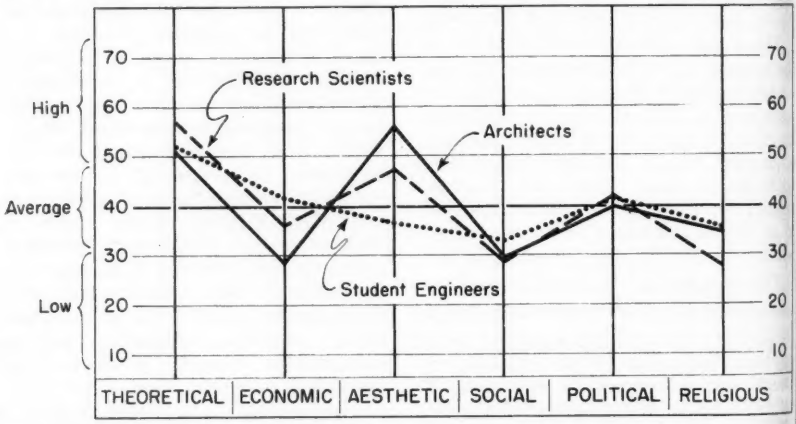
[3] The study of architects has been conducted by the present writer in collaboration with Dr. Wallace B. Hall.

more original subjects are less interested in small detail, in facts as such, and more concerned with their meanings and implications, possessed of greater cognitive flexibility, and characterized by verbal skills, and interest as well as accuracy in communication with others.

Architects match this pattern of high and low scores on the *Strong Vocational Interest Blank* most closely. The match is somewhat less good for research scientists, and least close for student engineers. The traits to be inferred from this particular pattern of scores are, then, somewhat less characteristic of student engineers than of research scientists and architects.

If more original persons are distinguished from less original individuals in terms of interests as measured by the *Strong Vocational Interest Blank,* one might also expect more creative individuals to have a pattern of values different from less creative persons; and indeed they do.

Eduard Spranger, the German psychologist, has described six basic values of men: the theoretical, the economic, the aesthetic, the social, the political, and the religious. The *Study of Values,* a test devised by Allport, Vernon, and Lindzey (1951), measures the relative strength of these six values in the individual. To simplify the presentation of scores on this test I shall in Figure 1 report data only for the 40 creative architects, the entire sample of 45 research scientists, and the 40 student engineers. Creative architects and research scientists as well as all other creative groups we have studied show on this test an elevation on both theoretical and aesthetic values. As you will see in Figure 1, the highest value for research scientists is theoretical (57.0) followed by aesthetic (47.5); for architects the aesthetic value is the highest (56.2) with the theoretical value in second place (50.8); while for creative mathematicians the two values are approximately equally high (aesthetic 54.7, theoretical 52.9). The other values tend to be low, and their slight variations in strength from group to group need not concern us here.



40 Architects	50.8	28.4	56.2	29.8	40.0	34.8
45 Research Scientists	57.0	36.3	47.5	29.1	41.9	28.1
40 Student Engineers	51.8	41.6	36.6	33.1	41.5	35.4

Profiles of Values on the Allport–Vernon–Lindzey Study of Values

Figure 1

The simultaneous high valuing of the theoretical *and* the aesthetic by all of our creative groups is especially interesting since the authors of the test assert that 'the aesthetic attitude is in a sense diametrically opposed to the theoretical; the former is concerned with diversity, and the latter with identities of experience" (Allport, Vernon, and Lindzey, 1951, p. 13). They describe the dominant interest of the theoretical man as the discovery of *truth*, that of the aesthetic man as *form* and *beauty*. The theoretical man is thought of as having a highly-developed cognitive attitude, seeking only to observe and to reason, and being unconcerned with either the beauty or the utility of objects. The aesthetic man, on the other hand, is pictured as one who judges all experience from the standpoint of fitness, grace, and beauty. If there is indeed for most persons some conflict between theoretical and aesthetic values, it would appear that one characteristic of the creative person is the capacity to tolerate the tension of opposed strong values and to effect some integration, synthesis, or reconciliation of them. For the truly creative person it is not sufficient that a problem be solved; there is the further demand that the solution be elegant.

It is interesting to compare the profile of values of student engineers with that of highly creative groups. The highest value of student engineers is, like that of the creatives, the theoretical; but the aesthetic is not highly valued by them. Instead, the economic (41.6) and the political values (41.5) tie for second place. Then, very much less pronounced are the aesthetic (36.6), the religious (35.4) and the social (33.1) values. Student engineers, it would appear, are less interested in form and harmony, in aesthetically pleasing and elegant solutions. Instead their interest focuses upon what is useful and productive (the economic value) and the exercise of power and influence (the political value). The aesthetic viewpoint permeates all of the work of our mature creative subjects, but not of the student engineers.

Something of this same difference is revealed on another test administered in our studies: the Barron Welsh Art Scale of the Welsh *Figure Preference Test* (Barron and Welsh, 1952) which requires of the subject that he designate as "Liked" or "Disliked" each of 62 abstract line drawings which range from simple and symmetrical to complex and asymmetrical. In the original study which standardized this test some 80 painters in New York, San Francisco, New Orleans, Chicago, and Minneapolis showed a marked preference for the complex and asymmetrical figures. A contrasting sample of non-artists revealed a marked preference for the simple and symmetrical drawings. The scale, originally standardized as a test of artistic interest and ability, has shown itself to be more than this, namely, a measure of creative talent.

On this scale, it is not surprising to find artists, as shown in Table 1, receiving the highest mean score (39.1), but what is especially interesting is that when we have groups from a single profession, one more creative than the other, the more creative sample scores higher than the less creative sample on this scale. Creative architects score 37.1, testing very close to the artists, while architects unselected for creativity score only 26.1. Similarly highly-creative industrial researchers score 30.7 (next to creative writers) while industrial researchers of

TABLE 1

BARRON-WELSH ART SCALE: WELSH FIGURE PREFERENCE TEST MEAN SCORES AND STANDARD DEVIATIONS FOR VARIOUS GROUPS

Group	N	Mean	S D.
Artists	30	39.1	—
Creative Architects	40	37.1	9.8
Creative Writers	20	31.5	12.5
Research Scientists (High creativity)	15	30.7	10.4
Women Mathematicians	41	27.0	14.7
Architects in general	41	26.1	12.1
Student Engineers	40	21.5	11.8
Research Scientists (Low creativity)	15	19.2	8.7
Non-artist (standardizing sample)	30	18.4	—

lower creativity score only 19.2 (next to the standardizing sample of non-artists). Student engineers as a group score slightly higher than the industrial researchers of low creativity, namely 21.5, but still relatively low as compared to our several creative samples. This is congruent with the student engineers' relatively low aesthetic value on the *Study of Values*, and like that finding suggests that student engineers need stimulation of their aesthetic interest and appreciation if their creative potential is to be developed.

If one considers the psychological meaning of the preference for the involved complex and asymmetrical as against the more orderly, simple and symmetrical figures, the differential scores on the Art Scale suggest that creativity is characterized by a disposition to welcome and to admit into the perceptual system complexity and some degree of disorder without experiencing unpleasant tensions or anxiety. In short, the creative person appears to have both a strong need and a superior capacity to achieve the most far-reaching ordering of the richness admitted into experience and to discover higher-order integrating and reconciling principles.

On the *Myers-Briggs Type Indicator* (Myers, 1958), a test designed to place individuals in the scheme of personality types developed by the Swiss analytical psychologist, Carl G. Jung, the similarities and differences between our several samples are rather intriguing.

In the language of this test it may be said that whenever a person uses his mind for any purpose he performs either an act of perception (he becomes aware of something) or an act of judgment (he comes to a conclusion about something). And most people are inclined to show a rather consistent preference for and greater pleasure in one or the other of these, preferring either to judge or to perceive.

An habitual preference for the judging attitude may lead to some prejudging, and in any case to the living of a life that is controlled, carefully planned, and orderly. A preference for the perceptive attitude results in a life that is more open to experience both from within and from without, and characterized by flexibility and spontaneity. A judgmental type will place more emphasis upon the control and regulation of experience, while a perceptive type is inclined to be more open and more receptive to all experiences and to seek to know as much as possible about life.

As may be seen in the Judgment-Perception columns of Table 2, creative architects (Architects I) tend to be perceptive types, 58 per cent of them preferring perception to judgment, while of the 41 architects unselected for creativity 81 per cent are judgmental.

Research scientists tend to be judging types, whether high in creativity (Research Scientists I) or low in creativity (Research Scientists II). Though still constituting the minority of research

TABLE 2

PERCENTAGE DISTRIBUTIONS OF THE PREFERENCES ON THE MYERS-BRIGGS TYPE INDICATOR FOR SAMPLES INDICATED*

Sample	N	Extraversion-Introversion		Sensation-Intuition		Thinking-Feeling		Judgment-Perception	
Architects I.	40	35	65	0	100	50	50	40	58
Architects II.	41	32	63	39	59	51	46	81	17
Research Scientists I.	15	33	67	0	100	67	27	60	40
Research Scientists II.	15	40	60	13	80	87	13	67	33
Student Engineers.	40	32	68	40	58	65	30	40	52

* Percentages of preferences for a given sample do not always sum to 100 since subjects may fail to show a differential preference for any one of the four pairs of opposites which determine an individual's type.

scientists, perceptive types occur among the more creative slightly more often (40%) than among the less creative (33%).

There is a slight tendency for the students to favor perception (52%) rather than judgment (40%). Since we know, however, that people tend to become somewhat more judgmental with age, this very slight favoring of a perceptive open-mindedness may well disappear by the time these students reach the age of the research scientists.

The second preference in this scheme is for one of two types of perception: sense-perception or sensation, which is a direct becoming aware of things by way of the senses, *vs.* intuitive perception or intuition, which is indirect perception of the deeper meanings and possibilities inherent in things and situations.

Preliminary norms for this test suggest that three out of four persons in the general population will be classified as sense perceptives. They concentrate on things as they are experienced through their five senses, and they center their attention on existing facts. The one out of every four who perceives intuitively looks expectantly for a link or bridge between that which is given and present and that which is not yet thought of, focusing habitually upon possibilities. Among college students and college graduates the percentage of intuitive types increases markedly.

There is no doubt that we would expect creative persons not to be stimulus- and object-bound but alert to the as-yet-not-realized; and indeed 100 per cent of the creative architects (Architects I) and 100 per cent of the more creative research scientists (Research Scientists I) are intuitives rather than sense-perceptives. It is noteworthy that 80 per cent of the research scientists who receive the lower ratings on creative originality are also intuitive. In view of these findings it is interesting to note that the percentage of intuitives among architects unselected for creativity is only 59 per cent, practically identical with the percentage of intuitives among student engineers (58%).

If we use sense-perception to tell us what is and intuition to tell us what may be, we use thinking and feeling in judging and evaluating our experience. This is the third preference in psychological functioning which everyone shows. Thinking-judgment or thinking is a logical process, aimed at an impersonal fact-weighing or analysis. Feeling-judgment or feeling is a process of appreciation and evaluation of things which gives them a personal and subjective value.

The thinking-feeling columns of Table 2 indicate that research scientists and student engineers tend to be thinking types. Artists, we know, show a preference for feeling. And since architects have to be both artists and engineers, and some are more of one and others more of the other, it is intriguing to discover that in both samples of architects the preference is about evenly divided between thinking and feeling.

The final preference in Jungian typology is the well-known one between introversion and extraversion. The extravert's primary interests lie in the outer world of people and things, while the introvert's primary interests lie in the inner world of concepts and ideas.

All three of our groups are inclined toward introversion and with about the same frequency. This finding jibes with other test results which indicate a frequent introverted orientation and desire for aloneness and independence on the part of our creative subjects. On one test of interpersonal behavior, for example, our creative architects revealed even less desire to be included in group activities than that expressed by the naval and civilian personnel who volunteered to man the Ellsworth Station outpost in Antarctica during the International Geophysical Year. Note, however, that a lack of interest in group activities need not imply a lack of interpersonal skills. When the creative architect has to interact with others he often does so in a dominant manner with marked social pressure and sometimes with consummate skill.

A fundamental characteristic of our creative subjects is a strong motivation to achieve in situations in which independ-

ence of thought and action are called for, and they show much less interest in or motivation to achieve in situations which demand conforming behavior (Gough, 1957).

A glance at the life histories of our creative subjects reveals that certainly not all of them had the kind of happy homes and favorable life circumstances so generally thought to be conducive to sound psychological development. Some experienced rather brutal treatment at the hands of their fathers. These, to be sure, constitute the minority, but they appear today no less creative than those whose fathers offered them quite satisfactory male figures with whom easy identification could be made, though there is some evidence that they are not so effective or so successful in their profession as the others.

Settling upon their life careers came early for some, one of whom already at four had decided he wanted to be an architect. Others were slow in coming to a professional identity, not deciding until several years past college that architecture was what they wanted to practice. In the case of several of these, the choice of a life profession was made the more difficult by virtue of the fact that they possessed so many skills and interests, providing them with the possibility of many quite different careers.

But our present interest is upon the careers of our subjects as students, and in this connection we may note that though the research scientists tended to be honor students in high school, they report having been unhappy during this period both at school and at home. In college their academic performance worsened; few of them were honor students and most earned no better than a *C+* to *B—* average, grades which would hardly admit them to graduate study today. There is some hint that they were more inclined to follow their own interests and independently explore problems of their own setting.

Our creative architects performed somewhat better academically in college, averaging about a *B*. But in their college work they were even more independent

TABLE 3

MINNESOTA MULTIPHASIC PERSONALITY INVENTORY MEAN STANDARD SCORES ON THE MF (FEMININITY) SCALE FOR VARIOUS GROUPS

Group	N	Mean
Creative Architects	40	72
Architects in General	41	65
Research Scientists	45	67
Student Engineers	40	63

than the research scientists. In work and courses which caught their interest they could turn in an *A* performance, but in courses that failed to strike their imagination, they were quite willing to do no work at all. In general, their attitude in college appears to have been one of profound skepticism. They were unwilling to accept anything on the mere say-so of their instructors. Nothing was to be accepted on faith or because it had behind it the voice of authority. Such matters might be accepted, but only after the student on his own had demonstrated to himself their validity. In a sense, they were rebellious; but they did not run counter to the standards out of sheer rebelliousness. Rather, they were spirited in their disagreement and one gets the impression that they learned most from professors who were not easy with them. But clearly many of them as students were not easy to put up with. One of the most rebellious, but as it turned out, one of the now most creative, was advised by the dean of his school to quit because he had no talent; and another, having been failed in his design dissertation which attacked the stylism of the faculty, took his degree in the Art Department.

In the realm of their sexual identifications and interests, our creative subjects appear to give more expression to the feminine side of their nature than do less creative persons (Table 3). On the Mf (femininity) scale of the *Minnesota Multiphasic Personality Inventory* (Hathaway and McKinley, 1945), creative architects have a mean standard score of 72, architects in general a mean standard score of 65, where 50 is the norm. On the

same scale research scientists earn a mean score of 67, student engineers 63.

Similarly on the Fe (femininity) scale of the *California Psychological Inventory* (Table 4), mean standard scores for the several samples, where 50 is again the norm, are: creative architects 57, architects not selected for creativity 52, research scientists 53, student engineers 46.

TABLE 4

CALIFORNIA PSYCHOLOGICAL INVENTORY MEAN STANDARD SCORES ON THE FE (FEMININITY) SCALE FOR VARIOUS GROUPS

Group	N	Mean
Creative Architects	40	57
Architects in General	41	52
Research Scientists	45	53
Student Engineers	40	46

From these data it would appear that more than most, creative persons are able to recognize and give expression to all aspects of inner experience and character, including the feminine, admitting into consciousness and behavior much which others would repress. If one were to cast this into the language of C. G. Jung, one would say that creative persons are not so completely identified with their masculine *persona* roles as to blind themselves to or deny expression to the more feminine traits of the *anima*. For some of the most creative the balance between masculine and feminine traits, interests, and identifications is a precarious one, and for several it would appear that their presently-achieved reconciliation of these opposites of their nature has been barely achieved and only after considerable psychic stress and turmoil.

Intelligence and Creativity

Concerning intelligence as a predictor and as a component of creativity, I have so far said nothing, for the simple reason that it is by no means the case that the most intelligent persons are the most creative. If they were, the identification and development of creative talent in our students would be simple indeed.

Over the whole range of intelligence one would expect to find a positive correlation between general intellectual ability and creativity. No feeble-minded subjects have turned up in any of our samples selected for their creativeness.

Yet look at Table 5, which lists the mean total scores for several ability groups on the Terman *Concept Mastery Test* (1956), a high-ceiling test of verbal intelligence. It is not surprising that on such a test creative writers outstrip all others. But it is interesting to note that the group with the second highest mean score, the subjects in Lewis M. Terman's (1957) study of the intellectually gifted, has fewer highly-creative persons than one would expect to find in a group so superior in intelligence. On the other hand, the architects, one of the most creative of our groups, earn a mean score of only 113.2, with individual scores ranging widely from 39 to 179. And in this group creativity in architecture as rated by a panel of experts correlates −.08 with scores on the *Concept Mastery Test*, a value not far different from the correlation between intelligence and creativity in our other creative groups. For the research scientists the intercorrelation of the two variables is −.07. These correlations are not significantly different from

TABLE 5

MEAN SCORES AND STANDARD DEVIATIONS FOR VARIOUS GROUPS ON THE CONCEPT MASTERY TEST, FORM T

Group	N	Mean	S.D.
Creative Writers	20	156.4	21.9
Subjects of Stanford Gifted Study	1004	136.7	28.5
Women Mathematicians	41	131.7	33.8
Graduate Students	125	119.2	33.0
Research Scientists	45	118.2	29.4
Creative Architects	40	113.2	37.7
Undergraduate Students	201	101.7	33.0
Spouses of Gifted Subjects	690	95.3	42.7
Electronics Engineers and Scientists	95	94.5	37.0
Engineering College Seniors	40	80.4	27.9
Military Officers	344	60.3	31.6
Independent Inventors	14	50.8	34.7

zero. It is rather clear that a certain amount of intelligence is required for creativity, but beyond that point being more or less intelligent is not crucially determinative of the level of an individual's creativeness.

The mean score of the engineering college students at Berkeley, 80.4, is less an indication of low intelligence on the part of these students than it is an indication of the narrowness of their intelligence. The *Concept Mastery Test* is described as "a measure of ability to deal with abstract ideas at a high level" (Terman, 1956, p. 3). It consists of two parts: Part I, Synonyms-Antonyms, is essentially a vocabulary test of knowledge; Part II, Analogies, is a test of word knowledge, general information, and reasoning ability. On such a test of verbal intelligence and range of information, student engineers reveal the narrowness of their interests and information.

On other less verbal tests of intellectual functioning included in our battery, they do relatively very much better. And on the *Minnesota Engineering Analogies Test, Form F* (Dunnette, 1955), which "combines features of an abstract reasoning test with those of a comprehensive engineering achievement test," they do very well indeed, as Table 6 indicates.

TABLE 6

MINNESOTA ENGINEERING ANALOGIES TEST, FORM F, MEAN SCORES AND STANDARD DEVIATIONS FOR VARIOUS GROUPS

Group	N	Mean	S.D.
Engineering College Seniors (U.C. Berkeley)	40	35.5	4.2
Research Scientists	45	35.0	6.5
Engineering Graduate Students	62	34.1	6.5
Engineering College Seniors	132	28.9	6.5
Employed Engineers	174	27.2	8.0

Another indication of the cultural narrowness of engineering students is their mean score as compared to that of other groups on the *General Information Survey* (Gough, 1954), a test of range of information in some sixteen areas of general and cultural interest: art, athletics, ballet, clothes and clothiers, food, history, household goods, liquor and wine, local and regional lore, mores, music, mythology, recreation, religion, science, and theater. On this test the mean score for research scientists is 46.11 (S.D. 8.55), for creative architects 42.22 (S.D. 6.65), but for our student engineers only 36.08 (S.D. 7.25).

These findings concerning the intellectual competence and achievements of senior engineering students make one wonder whether the bases for selection of students for admission to the College of Engineering and the curriculum which they experience there are not too narrow. Is it possible that the intellectual promise and creative potential of students of engineering are conceived too narrowly and identified in the minds of their instructors with academic achievement in engineering subjects? Our data suggest that this is indeed the case.

It is a characteristic of assessment studies that the psychological assessors are kept in ignorance of the relative standing of subjects on the major dimension under investigation. Indeed, criterion measures of creativity have been collected only after our assessments have been completed, or, if available earlier, have not been made known to the staff until all of their impressions have been recorded.

It is of some interest to inquire, then, as to what agreement exists between the ratings of originality and creativity given by us and those made independently by the experts for our several samples. In our study of engineering students the psychiatric life-history interviewers' ratings of subjects' originality correlated +.00 with faculty ratings of the same, and ratings of originality given by staff members (excluding the interviewers) also correlated +.09 with faculty ratings.

Such zero relationships between our impressions of the originality of our subjects and the judgments of the "experts" are, however, most unusual. In the case

of the research scientists our ratings of originality correlated +.30 with the outside criterion, a positive relationship which though low is statistically significant. In the case of the architects, staff ratings of their originality correlated +.61 with the experts' ratings of creativity.

The engineering faculty's conception of creative originality is obviously quite different from ours, and by inference different also from other "experts'" notions about creativity. How do they conceive creative originality in their students? A partial answer to the question can be found in an examination of those variables with which their ratings of creative originality are highly correlated. Here they are: +.73 with grade point average, +.77 with faculty rating of scientific productiveness, +.82 with scholastic performance (faculty rating plus GPA), and +.84 with faculty rating of scientific competence. And these are just about all the variables with which faculty ratings of creative originality show any significant and sizable correlations. The conclusion is inescapable: for the engineering faculty the creativity of their students is not distinguishable from and therefore is largely equated to their achievement in engineering courses. It would appear that students are selected on the basis of their engineering aptitude and achievement and it is for this that they are rewarded in the course of their training.

Selecting Creativity

And what, we may now ask, are the implications of the findings which I have reported to you for the identification and development of creativity in students of engineering?

The fostering of creativity in schools and colleges of engineering requires first that students with creative potential be selected for admission. Our evidence suggests that criteria for selection are highly fallible and leave much to be desired. The tendency at present, it would appear, is to favor applicants who score high on tests of scholastic aptitude but more specifically on tests of engineering aptitude and achievement. One would hardly suggest that aptitude for engineering or achievement in the subject are irrelevant factors or that they should be ignored, but one might well raise the question whether these indices alone identify students with creative potential.

I think our findings with respect to intelligence suggest that creative subjects are in the main well above average on this dimension. Their brains have an unusual capacity to record and retain and have readily available the experiences of their life histories. The intelligent person is more discerning (more observant in a differentiated fashion), he is more alert (can concentrate attention readily and shift it appropriately), and he is more fluent in scanning thoughts and producing those which meet some problem-solving criterion. Such a person will generally have more information (in the most general sense of the term) at his command. Furthermore, items of information which he does possess may more readily enter into combination among themselves, and the number of possible combinations is increased for such a person both because of the greater information and the greater fluency of combination. Since true creativity, as I have indicated, is defined by the adaptiveness of a response as well as its unusualness, it is apparent that intelligence alone will tend to produce greater creativity. The more combinations that are formed, the more likely it is that some of them will be creative.

But if range of information, interests, and skills are narrow and within a single field of knowledge, the number of items available for new combinations may well be inadequate to the demands of the situation requiring a creative solution. A broadening of interests both within the classroom and in the intellectual climate of the school seems clearly indicated.

But intelligence alone does not make for creativity. Some of our most creative subjects score lower on measures of intelligence than do some of our less creative subjects. What seems to characterize the more creative person is a relative absence of repression and suppression as mechanisms for the control of impulses and images. Repression operates against creativity regardless of how intelligent a

person may be because it makes unavailable to the individual large aspects of his own experience, particularly the life of impulse and experience which gets assimilated to the symbols of aggression and sexuality. Dissociated items of experience cannot then combine with one another; there are barriers to communication among different systems of experience. The creative person, who does not characteristically suppress or repress, but rather *expresses,* has more available to him his own unconscious, and thus has fuller access to his own experience. Furthermore, because the unconscious operates more by symbols than by logic, the creative person is more open to the perception of complex equivalences in experience, facility in poetic metaphor being one consequence of the creative person's greater openness to his own depths.

What to me is most strongly suggested by our findings is that we should seek to develop in students a capacity for intuitive perception and intuitive thinking, an immediate concern for implications, and meanings, and significances, and possibilities beyond that which is presented to the senses. This is not to suggest a slighting of facts, for there is a great wealth of information which every educated person must possess. Without a richness of experience, which includes a considerable body of fact, and especially so in engineering, intuitions may be original but they are not likely to be very creative. But I would urge that in our instruction and in our training we never present a fact for its own sake, and that in our testing of our students' knowledge we shun questions which require no more than identification of facts and formulas. I am convinced that we can measure information which students have learned more reliably, more validly and more economically by objective tests than by essay examinations. But it remains true, I believe, that a student's preparation for and actual writing of an examination which requires dealing with problems forces him to exercise his intuitive perception.

Rote-learning, learning of facts for their own sake, repeated drill of material, too much emphasis upon facts unrelated to other facts, and excessive concern with memorizing, can all strengthen and reinforce sense-perception. On the other hand, emphasis upon the transfer of training from one subject to another, the searching for common principles in terms of which facts from quite different domains of knowledge can be related, the stressing of analogies, and similes, and metaphors, a seeking for symbolic equivalents of experience in the widest possible number of sensory and imaginal modalities, exercises in imaginative play, training in retreating from the facts in order to see them in larger perspective and in relation to more aspects of the larger context thus achieved; these and still other emphases in learning would, I believe, strengthen the disposition to intuitive perception and intuitive thinking.

If the widest possible relationships among facts are to be established, if what I would call the structure of knowledge is to be grasped, it is necessary that the student have a large body of facts which he has learned as well as a large array of reasoning skills which he has mastered. You will see, then, that what I am proposing in teaching is not that we slight acute and accurate sense-perception, but that we use that to build upon, leading the student always to an intuitive understanding of that which he experiences.

I would remind you that "ledge," the second element in the word *knowledge,* means sport. "Knowledge is the result of playing with what we know, that is, with our facts. A knowledgeable person in science is not, as we are often wont to think, merely one who has an accumulation of facts, but rather one who has the capacity to have sport with what he knows, giving creative rein to his fancy in changing his world of phenomenal appearances into a world of scientific constructs" (MacKinnon, 1953, p. 145). And so it is in all fields, not science alone.

While our data suggest that a rich development of intuitive powers facilitates creativity, they do not deny the necessity of accurate sense-perception. It is a matter of which gets emphasized.

So, too, with the perceptive and judg

ing attitudes, both of which each of us possesses and uses but to different degrees. One must often enough judge and evaluate one's own experience, but it is important that we not prejudge, thus excluding from perception large areas of experience. The danger in all academic instruction is that we criticize new ideas too soon and too often. Training in criticism is obviously important and so much emphasized that its case need not be pleaded. Rather I would urge that an equal stress be placed on perceptive open-mindedness, discussing with students at least upon occasion the most fantastic of ideas. It is our duty as professors to profess what we have judged to be true, but it is no less our duty by example to encourage our students to be open to all ideas and especially to those which most challenge and threaten our own judgments. We give lip service to the university as the testing ground for new ideas, but too often our emphasis is upon testing rather than on new ideas.

I am struck by the discrepancy between the scores our creative subjects earn on the achievement via independence and the achievement via conformance scales of the *California Psychological Inventory*. And I am also struck by the descriptions of their behavior when in college. These data are congruent with all our observations in assessment which suggest that these subjects are now and for a long time have been independent characters. It is an independence which manifests itself not in footless rebellion but in the accomplishment of goals which the individual sets himself and which he achieves in his own unique fashion. I would infer from this that if we are to encourage creativity in college students we must give them a maximum of freedom in achieving their educational objectives.

It is our task as educators to set goals for the college and for the individual courses. The goals, I believe, should be set in only the most general fashion, but they must be set high enough to challenge the student and to involve him in the overcoming of obstacles.

More specifically I would suggest that no course or seminar deserves a place in a college curriculum unless it requires of the student the solution of some problem —a research project, a term paper, etc. The requirement, stated in only the most general fashion, permits the student to determine what specifically his own problem will be. Thus he chooses, he sets the problem, and having done so, he might well be left to solve it in his own way. Thus we would provide the student with what I believe to be one of the necessary conditions for creative achievement: the undertaking of the solution of a problem where the degree of difficulty and frustration is great and the drive toward accomplishment is persistently strong.

If goals are set high enough, repeated periods of frustration will be experienced. It is at these times which I have called periods of withdrawal from the problem that the college community, if it is a stimulating intellectual environment, can contribute importantly to the nourishment of creativity. For it is often in these periods of renunciation of the frustrating problem that those accidents which induce sudden insight and are thus not accidents at all, since one is set for them, occur.

This, as I see it, is the meaning of serendipity, the finding of valuable or agreeable things not sought for. If, when a student withdraws from a problem which has repeatedly frustrated his attempts at solution, he moves in an environment alive with ideas and stimulating conversation, the chances of the insight-inducing accident's occurring are made greatest.

Finally, I think our data should remind us that our creative students may not always be to our liking. Almost certainly we will at times find them difficult to get along with. But if we recognize that some of their behavior which may be most irritating to us arises out of a struggling attempt to reconcile opposites in their nature and to tolerate large quantities of tension as they strive for a creative solution to difficult problems which they have set themselves, we may be in a better position to support and encourage them in their creative striving.

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NSPE TO CERTIFY TECHNICIANS

The NSPE has authorized the establishment of an Institute for the Certification of Engineering Technicians, the purposes of which are: (1) elevate the performance standards of engineering technicians as an important part of the engineering team; (2) determine the competence of engineering technicians through investigations and examinations to test the qualifications of voluntary candidates for certificates to be issued by the Institute, as hereinafter set forth; and (3) grant and issue certificates to engineering technicians who voluntarily apply therefor and maintain a registry of holders of such certificates.

The Institute is an examining and certifying body only which will determine qualification for three classes of technician upon voluntary submission of credentials by a person seeking such recognition. It is not another technical society, nor is it a class of membership in NSPE.

Persons engaged in the practice of engineering are excluded from consideration since matters in the professional realm fall under the jurisdiction of the various state boards of engineering examiners. To make certain that no confusion exists and that there is no misunderstanding on the part of the certificate holder, or misrepresentation on their part, each certificate "shall carry thereon a statement to the effect that such certification does not constitute a license to practice engineering." (Rules of Procedure, Section 5)

Career Choice and Curriculum Evaluation[1]

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When a freshman begins a program of professional education, what determines his reactions to his chosen program of study? At that time he has undoubtedly begun to form an image of his vocation which influences his decisions about education and curriculum. If we question him about what he would consider ideal in his chosen curriculum, we discover in his answers some reflections of that image and some implications for the kind of curriculum he believes he needs to realize it.

Suppose also that we question him about what he expects realistically. We would see by his answers that he expects some of his desires to be fulfilled but that he also anticipates certain discrepancies between his ideal and the education he will actually receive.

The data to be discussed were obtained from students at Case Institute of Technology, an engineering school in Cleveland with a total enrollment of approximately 1600 undergraduates of whom 500 are admitted as freshmen each fall. In January, 1959, a questionnaire was administered to all freshmen and returns were obtained from over 80 per cent of them. Since this was before the end of the first semester, almost no students had yet withdrawn.

For convenience in analyzing our data, some of the ten curricula available were grouped on the basis of certain similarities. For example, all *science* curricula were combined to include physics, mathematics, chemistry, and science engineering. *Electrical* and *mechanical engineering* were treated as separate entities because each is chosen by a substantial number of students and both were in the process of revision and transition. The fourth grouping, *general engineering*, includes civil, chemical, and metallurgical engineering. Each of these was chosen by a relatively small number of students and its contents were fairly constant at the time of the study.

Student Views of the Ideal Curriculum

To obtain information about the student's ideal in curricula, this was the procedure followed. Thirteen attributes that are characteristic, in greater or lesser degree, of any curriculum were selected. Each was defined by short descriptive phrases at both extremes of an eight-point rating scale. The student circled the number on the scale which he felt best represented how his curriculum ranked in that attribute. The thirteen attributes fall into three broad categories that pertain to (1) skills or subject matter that are essential to one's future professional function (ratings 1, 2, 5, 12, and 13); (2) certain secondary skills and subjects (ratings 4, 7, 9, 10, and 11); and (3) the organization and administration of the curriculum

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TABLE 1—STUDENT VIEWS OF THEIR CHOSEN CURRICULUM: IDEALLY AND REALISTICALLY

Curriculum Characteristic	Curriculum Group											
	Science N = 145		Gen. Eng. N = 67		Elect. Eng. N = 97		Mech. Eng. N = 93		Management N = 47		Total N = 449	
	I	R	I	R	I	R	I	R	I	R	I	R
1. Theory vs. Practice	3.2	2.7	5.0	4.4	4.2	3.4	5.2	4.0	5.4	4.5	4.4	3.7
2. Broad vs. Direct Relevance	2.8	2.8	3.4	3.6	3.6	2.9	3.4	2.8	3.0	2.6	3.3	2.9
3. Freedom of Choice yes —> no	2.0	3.7	3.4	5.4	2.6	4.6	3.1	4.7	1.9	3.9	2.6	4.5
4. Emphasis on Citizenship no —> yes	4.4	3.1	4.5	3.3	2.6	4.6	3.5	3.6	3.1	2.8	3.7	3.2
5. Thinking vs. Facts and Techniques	2.2	2.7	3.9	4.1	3.7	3.0	3.5	3.4	3.2	3.4	3.1	3.1
6. Difficult vs. Easy	2.2	1.4	2.9	1.9	2.9	1.5	3.1	1.5	3.2	1.8	2.7	1.5
7. Emphasis on Ability to Express yes —> no	1.6	2.8	1.8	2.5	1.7	2.2	1.4	3.2	1.0	2.2	1.6	2.7
8. Emphasis on Integration yes —> no	1.8	3.1	2.3	3.0	1.7	2.2	2.5	3.6	1.7	3.2	2.0	3.2
9. Emphasis on Understanding People yes —> no	2.7	3.3	2.4	3.2	2.8	3.5	2.1	3.7	0.9	2.0	2.4	3.3
10. Emphasis on Management yes —> no	3.3	4.8	2.2	2.8	2.3	3.4	1.8	3.3	0.7	1.6	2.1	3.3
11. Technical vs. Humanities Emphasis	3.3	2.5	3.0	2.6	2.7	3.0	3.0	2.7	4.4	3.4	3.1	2.9
12. Emphasis on New Developments yes —> no	1.0	2.0	1.9	2.4	1.8	2.4	1.8	2.5	2.1	2.8	1.7	2.3
13. Opportunity to Specialize yes —> no	2.4	2.7	3.0	4.0	2.7	2.9	3.1	3.6	4.1	3.7	3.0	3.2

* Columns labelled "I" refer to "Ideal" ratings and "R" to "Realistic" ratings.

itself as a whole (ratings 3, 6, and 8). Separate tabulations of median responses for each curriculum group have been made and are summarized in Table 1.[2]

We shall examine, first of all, the pattern of choices made by the science students and the long-range vocational image implied. As for a central core of skills, science students place more importance than other groups do on theory, on broad professional training, and on being prepared for new developments in their fields. They express the greatest interest in ideas or abstractions and the least interest of any group in practical techniques that could have direct utility for some jobs they might later hold. They also express the greatest interest of any curriculum group in broad problem-solving methods. They, in company with the electrical engineering students, favor an opportunity to specialize during college but not to the extent that other groups do. According to these findings, the science students need not be judged impractical or unworldly, but as perhaps having a greater appreciation for the long-range utility of theory and problem-solving methods than for that of specialized applied skills.

Among the more peripheral aspects of the science curriculum, some questions referred to secondary but job-related skills and some to knowledge that is unrelated to professional training. For example, ratings 4 and 11 concern one's role as a citizen and the value of studying humanities. For want of a better phrase we refer to these as universal areas of knowledge. The science students express as much interest in these as any of the groups but the least interest in secondary job-related skills. They and the general engineering students are foremost in their emphasis on citizenship, and their interest in humanities is exceeded only by that of the management students for whom such knowledge may appear more job-related. Students in science curricula seem to define professional performance as primarily a matter of purely technical competence. They recognize that clarity of expression is important but are among the least interested in management skills (rating 13) and least expect human relationships (rating 9) to be important in their careers.

In the third category, attributes of course administration and organization, science students are most emphatic in wanting a difficult curriculum (rating 6) and are one of two groups most desirous of freedom to choose among the courses in their curricula. They hope that the required material will be well integrated, but are no more emphatic about this than the other groups.

Our second curriculum group, the electrical engineering students, resembles the science group yet differs in significant ways. The electrical engineers also recognize the importance of theory but with more utilitarian overtones. They are in second place in their emphasis on theory but second-to-none in desiring material of direct relevance whose application is clear. They are among the most interested in learning facts and techniques as distinct from problem-solving skills. Unlike the science students, who appear to view theory as a valued end in itself, the electrical engineers apparently value theory because of what one can do with it. Their emphasis on new developments is moderate, and like the science students, they are no more extreme in their desire to specialize than are other groups.

In ranking secondary skills, the electrical engineers reverse the pattern of the science students somewhat. While the science students were most interested in the areas of universal knowledge—humanities and citizenship—the electrical engineers are the least interested. But in their rankings of professionally relevant secondary skills, they are more like the science students. They have considerable interest in learning clarity of expression but place the least emphasis on understanding people and next to the least on management skills of any group. Perhaps they too see their profession as demand-

[2] In Table 1, each attribute is described by the pair of descriptive phrases with which it was defined. The left-hand number of the pair always refers to the low end of the rating scale, the right-hand number to the high end of the scale. In addition, median scores can range from a low of 0.5 to a high of 7.5.

ing technical proficiency and placing less of a premium on human relationships and management than do other engineering professions. The electrical engineers also want a relatively difficult curriculum and are very interested in the integration of material in their curriculum. They are moderately anxious to have some freedom of choice but less so than the science students.

In the evaluations by those in mechanical engineering and the general engineering curricula, we see a further progression away from theory and toward the development of practical skills. Students of chemical, civil, and metallurgical engineering (grouped as general engineering) want a curriculum that is more practical than theoretical, that emphasizes facts, techniques, and material of quite direct relevance. These students express as much interest in new developments and in specialization as do other groups. Mechanical engineering students share the opinions of general engineering students about the core content of their curriculum. They too are more interested in obtaining practical skills and in material of immediate relevance to their future work.

In the area of secondary skills, more differences can be observed between students in general vs. mechanical engineering, although both groups place the same relatively high value on technical preparation in contrast to humanistic studies. While those in general engineering show more interest in preparing for citizenship, the mechanical engineering students place more value on learning to express themselves, on administrative skills, and on understanding people.

Students in these two curriculum groups are least concerned with freedom to choose their courses. They favor "a well laid out program in which few choices are necessary." They prefer a program of studies that is not too difficult and, of all the curriculum groups, are the least concerned about integration of the subject matter.

There remain for discussion those students in the management curriculum. In some respects, they are even more practical than the engineers and are furthest removed from students in the sciences. They show the strongest interest in practical applicability of the material taught but are also highly interested in obtaining a broad knowledge of the field and in developing problem-solving skills. They are the least interested in new developments and the least desirous of an opportunity to specialize within the curriculum.

In the area of secondary skills, they have relatively little interest in their future roles as citizens but express by far the highest interest in humanistic studies. These latter evaluations are somewhat difficult to interpret. It may indicate that some already have interests that go beyond the confines of the traditional science and engineering courses, but some may value humanistic studies because they seem instrumental to a successful career. As one would expect, the management students show the greatest interest in learning to express themselves, in the development of managerial abilities, and in understanding people. While these skills are of secondary relevance for students in the science and engineering curricula, they are of more primary relevance for those students who are heading for careers in management.

The management students express the strongest desire for freedom of choice, perhaps because of the fear that their curriculum is, in part, weighted toward science and engineering in ways that will not serve their needs. They express the strongest interest in a curriculum that will not be too difficult and some concern about the integration of subject matter.

What Students Actually Expect in Curricula

After rating features that would be ideal, these students then rated the same attributes for the curriculum as they expect it will be in reality. These expectations are also summarized in Table 1. The data clarify the question of whether or not students are moderately realistic when they choose a given curriculum and to what extent their expectations conform to its actual content. In certain important

TABLE 2—STUDENT EXPECTATIONS OF DIFFERENCES BETWEEN THEIR "IDEAL" AND "REALISTIC" CURRICULUM

CURRICULUM CHARACTERISTIC	CURRICULUM GROUP					
	Science	Gen. Eng.	Elect. Eng.	Mech. Eng.	Management	Total
1. Theory vs. Practice	0.5	0.6	0 8	1 2	0 9	0 7
2. Broad vs. Direct Relevance	0 0	—0.2	0 7	0.6	0 4	0 4
3. Freedom of Choice yes —> no	—1.7	—2.0	—2 0	—1.6	—2.0	—1.9
4. Emphasis on Citizenship no —> yes	1 3	1 2	—2 0	—0 1	0 3	0.5
5. Thinking vs. Facts and Techniques	—0.5	—0.2	0 7	0.1	—0.2	0.0
6. Difficult vs. Easy	0.8	1.0	1 4	1 6	1.4	1.2
7. Emphasis on Ability to Express yes —> no	—1.2	—0.7	—0.5	—1 8	—1.2	—1.1
8. Emphasis on Integration yes —> no	—1.3	—0.7	—0 5	—1.1	—1.5	—1.2
9. Emphasis on Understanding People yes —> no	—0.6	—0.8	—0.6	—1.6	—1.1	—0.9
10. Emphasis on Management yes —> no	—1.5	—0.6	—1.1	—1.5	—0.9	—1.2
11. Technical vs. Humanities Emphasis	0.8	0.4	—0.3	0 3	1.0	0.5
12. Emphasis on New Developments yes —> no	—1.0	—0.5	—0.6	—0 7	—0.7	—0.7
13. Opportunity to Specialize yes —> no	—0.3	—1.0	—0.2	—0.5	0.4	—0.2

respects, students do appear to be aware of what they will encounter in their chosen curricula.[3] For example, the science students view their chosen curriculum as the most theoretical, those in electrical engineering as moderately theoretical, while those in other engineering or in management groups expect courses that stress practical affairs.

Yet our interest in asking these questions was not so much directed at assessing how realistic students' expectations were as toward discrepancies between the two sets of ratings—how much they expect the actual curricula to differ from what they view as ideal. Using the data from Table 1, for each rating scale we have subtracted the median response for each attribute as it is expected to rate in reality from the median for what is desired ideally. The results are tabulated in Table 2.

One notices first that the discrepancies between what they desire and what they expect are similar for students in different curricula, as demonstrated by the fact that for many pairs of ideal vs. real ratings, the differences are in the same direction for different curriculum groups.[4]

[3] However, from other more detailed analyses, we can show that significant numbers of students in any curriculum hold an image of their role as a professional that is inconsistent with their choice of a program of studies. What are the consequences of such inconsistent choices? At the present time we are unable to say, but the problems confronting these students are certainly worthy of further investigation.

[4] In testing for the significance of these differences, we have made use of the sign test described by S. Siegel, *Non-parametric Statistics*, New York, McGraw-Hill, 1956, pp. 68-75. In this test, one computes the direction of the difference (plus or minus) and determines whether or not the obtained frequency of differences could be explained on the basis of chance influences. Significance tests have been carried out for the student population as a whole and for each curriculum group. These results can be obtained by writing to the Department of Industrial Engineering, Northwestern University, Evanston, Illinois. In general, differences as large as $\pm$ 1.0 are highly significant, differences that do not exceed 0.3 to 1.0 are usually significant at either the .05 or .10 level of probability.

For example, the material with greatest professional relevance is expected by all groups to be too theoretical with insufficient emphasis on practical applications. The real approaches the ideal more closely for students in sciences and general engineering in this respect, however. It may be significant that students in the three curricula (electrical, mechanical, and management) where more emphasis on theory has recently been introduced are more concerned than other groups lest it be at the expense of practical applications.

Similarly, there is substantial agreement among the curriculum groups about two other areas of core, professional skills. Students in all curricula expect that there will not be enough emphasis on new developments and expect too much concern with presently accepted techniques. Students apparently do not expect the faculty to be able to keep up with new developments or to be completely successful in teaching them. As for opinions about breadth of training, the students in science and general engineering are apparently satisfied, while those in the three remaining curricula expect too much breadth and not enough attention to material of direct relevance to the work they think they will be doing.

As for the opportunity for specialization, students in the different curricula do not agree on the adequacy of their various programs. Students in science and electrical engineering expect their aspirations to be substantially satisfied. Perhaps they are influenced by the Case catalogue which says that the science curricula offer the students considerable freedom of choice while the electrical engineering program permits some choice among technical electives. However, those choosing either general engineering programs or mechanical engineering express the expectation that there will not be enough opportunity to specialize. Those in the management curriculum lean slightly in the opposite direction, tending to expect a little too much specialization.

There is one final question in the area of core skills which remains to be discussed, that of the relative emphasis on

the ability to think logically and abstractly. Students in general engineering, mechanical engineering, and management expect that their programs will place the proper emphasis on this ability. Only the electrical engineers fear an overemphasis at the expense of teaching facts and techniques that have direct application, while science students expect the opposite—insufficient emphasis on thinking logically and abstractly.

In their opinions about the secondary elements of the curricula, students in all programs show some agreement, particularly where professionally-relevant skills are concerned. All students expect a program of studies that will be too narrow and that will place insufficient emphasis on learning to express oneself, on management skills, and on learning to understand people. However, where the areas of universal knowledge are concerned, students in the different curricula show a less consistent pattern of responses. Those in science and general engineering expect much too little emphasis on preparation for one's responsibilities as a citizen. The students in management agree to a moderate extent while those in mechanical engineering expect that the emphasis will be "about right." The expectations of the electrical engineers are very much in the opposite direction: they feel rather strongly that the responsibilities of citizenship will be over-emphasized in their program of studies. There is a similar difference of opinion over how much attention should be given to the program of humanistic studies. All students except for the electrical engineers wish for a greater emphasis, while this latter group leans in the direction of desiring more emphasis on a strictly professional curriculum.

With respect to questions of course organization and administration, all students are in substantial agreement. They all desire greater freedom to choose for themselves and more opportunity to make up their own program of studies. They all wish that their programs would be a little less difficult. In these opinions, they are undoubtedly expressing the anxiety of freshmen about the possibility of surviving at Case. Finally, they all wish that their program of study would provide more help in integrating the material from separate courses.

Summary and Discussion

From these data one can draw certain interesting contrasts between students who choose a science curriculum and those in engineering. The science students are in many respects the "men of ideas," with their strong interest in theory and their relative indifference to empirical skills, while the engineering students are more "men of action" placing much greater value on what is practical and directly applicable. This is most true for students of mechanical engineering and moderately true of those in the general engineering group. Even the electrical engineers, who place greater emphasis on the importance of theory, appear to do so for reasons of utility rather than because they value theory for its own sake.

Students in science and engineering also differ in the degree to which they value training in skills of administration and management. The students choosing science and electrical engineering appear to define professional competence as primarily a matter of purely technical proficiency. Although they appreciate the importance of being able to communicate effectively, they express relatively less interest in administrative skills than do those in the other engineering curricula. Students of science are the most tolerant of courses designed to broaden their education in ways that have no direct relevance to their professional careers, for they are quite open to courses that concern their future roles as citizens and courses in the humanities and liberal arts. At the other extreme are those choosing mechanical and electrical engineering, while those in the general engineering curricula place an intermediate value on these courses.

In addition, it is the science students who are most concerned with freedom of choice and most willing to accept a program of studies that will be difficult, demanding, and challenging. The electrical engineers share in part these values. Students in the remaining engineering cur-

ricula are much more willing to let the faculty determine the content of their curricula. Moreover, they would prefer a program that is relatively less demanding and that would afford them some opportunity to engage in extracurricular activities. Final inferences from these data relate to important changes that are currently being introduced into many undergraduate engineering curricula. One such trend is toward increasing emphasis on the theoretical principles that underlie a given engineering discipline and a decreasing emphasis on specialization in undergraduate programs. There is considerable evidence from these data that students entering Case fear this trend and the impact it may have on their chosen curricula. Although science students favor the increasing emphasis on theory, engineering students very decidedly anticipate excessive emphasis on theory and insufficient emphasis on material of direct utility and immediate relevance to their careers. It is by no means our intention to suggest on the basis of these findings that engineering schools should modify their programs in order to conform to students' preferences. It is certainly conceivable that these students have insufficient appreciation for the practicality of a good theory. The resistance to this increasing emphasis on theory might well be diminished if students were made more fully aware of the reasons for the trend and of its potential value for them in their professional careers.

Another trend in engineering education is toward a "well rounded" education aimed at developing more than technical competence. It has led to the introduction of courses preparing students for administrative responsibilities and courses in the humanities. Most students accept the importance of administrative skills more willingly than that of humanities and liberal arts. There is an interesting paradox revealed by comparing what they desire with what they expect. Students in all the curriculum groups expect insufficient attention to be given to the development of skills in management, understanding people, and in communicating effectively. Is it possible that students have considerable anxiety about their ability to undertake administrative responsibilities and that engineering schools continue to underestimate how justified the anxiety may be? The data indicate that students feel that more changes should be made in their programs to fill this need. They also indicate that increased recognition of the importance of humanities would be acceptable. This view is most characteristic of those who choose programs in science. Most engineering students, however, think that sufficient emphasis is given to humanities, with the exception of the electrical engineering students who consider them over-emphasized.

There is one final issue that is often discussed but about which opinions differ. This is the question of how much freedom of choice within a given curriculum should be permitted the student. Most students at Case Institute agree—they desire more freedom to choose electives than they expect to have. Admittedly, there are sound reasons why current curricula contain many required courses. Yet students in all curricula express strong desires for more freedom of choice. At a school of engineering and science, it is particularly important that students maintain a high degree of interest. Perhaps if they were permitted more responsibility for selecting courses, they would be compelled to clarify for themselves what the demands of their profession are going to be and what they need to learn in order to fulfill those demands. Having thus participated in defining their own individual goals and needs, students might feel a more intense personal involvement in reaching them.

EDUCATIONAL RESEARCH COUNCIL AT R.P.I.

Rensselaer Polytechnic Institute June 7 announced the establishment of an Educational Research Council designed to improve the Institute's educational programs and teaching methods.

Just Ahead – A Golden Age for Graphics

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Recently a faculty member asked me to help him solve, graphically, a stubborn differential equation. He told me that for weeks he, along with others, had attempted to solve it mathematically, but had made little progress. I asked him why he didn't program it on one of our computers and solve it that way. His answer, I thought, was quite significant. "I could," he said, "but it would require many hours of tedious work; the results need not be extremely accurate; and I might still have to plot the answer, since I want to test for oscillatory functions. So it seems as though the entire problem might just as well be solved graphically in the first place." And he could be right.

The actual equation cannot be presented in detail due to the classified nature of the research project with which the equation was connected. However, the differential equation involved was a reducible second order equation not containing the independent variable, which reduced to a first order equation containing both independent and dependent variables. *As such*, it could be easily solved. However, the "fly in the ointment" was the fact that it *also* contained three parametric constants, and the usefulness of the solution depended upon our being able to arbitrarily vary these parameters simultaneously. This turned a routine problem into a complicated one.

The foregoing is only one example of the sizable contribution computational graphics can make to future technological progress. I am convinced that at present only a small percentage of research scientists, practicing engineers, and engineering educators are aware of the full potential which exists in the graphics field. We know that mathematics is indispensable to a good background in science and engineering. I believe that graphics is also indispensable–if we use *good* in its proper sense.

We can divide the uses of graphics into three general categories: (1) orthogonal and pictorial projection, (2) solutions to engineering and research problems, (3) analysis of large quantities of data, abstract or otherwise. The first of these has been (and is being) taught in great detail. In fact, I suspect that many people think of graphics as being *synonymous* with engineering drawing, charts, maps, and so forth. But this idea omits the last two areas, and it is there that the graphicist can make his greatest contribution to our "space-tronic" technology.

To what extent has investigation been carried into possibilities in these disciplines? Is there any need for further research in the field of graphics? Everybody connected with engineering education should have an interest in these and similar questions. Anyone acquainted with graphics texts knows that the most recent revisions include material on empirical equations, graphical calculus, vector geometry and other fundamental subjects. As to the second question, asking whether there is a need for additional research is

Recommended for publication by the Engineering Graphics Division.

probably like asking whether there is room for improvement.

It is conceivable that a problem such as was mentioned at the beginning of my article *might* have a relatively simple graphical solution. Research into this general *type* would be helpful. The same thing can be said of other types of problems. If research into graphical methods is to be encouraged, some necessary steps should be taken. I suggest that at least the following be done:

1. Graphics instructors should become aware that many problems generally still solved by traditional methods are "naturals" for the relative simplicity and ease of graphical solution or analysis. Recent texts of college mathematics and physics are a fertile source of graphical material for instructional purposes.
2. Graphics meetings, conferences, and reports should emphasize the many new applications of graphics, rather than the established segments of the field.
3. Engineering educators should lend support to the efforts of forward-thinking graphics people, by making use of graphical solutions and analyses whenever these can make important contributions to the solving of problems.
4. Graphics departments should make the subject matter of their courses as timely as possible by incorporating problems related to mathematics, physics, mechanics, and the engineering-degree areas.

Present graphics courses in many engineering colleges are out of balance because they continue to emphasize only that portion of graphics known as "Engineering Drawing." The age-old resistance to change, inertia, is one of the main contributing factors to the present low academic prestige of graphics in scientific engineering. However, with a positive approach and a shift in emphasis to permit knowledge of *all* portions of graphics, there is every assurance that graphics will prove invaluable as a tool of research. In fact, graphics *may* be at the threshold of a golden era. We have hardly scratched the surface of what it *can* do. The basic requirements for crossing the threshhold are genuine interest, extensive curiosity, and vigorous activity.

UNIVERSITY OF ALASKA ESTABLISHES COLLEGES

In a move to streamline and consolidate the research, administrative and educational procedures of the University of Alaska, the Board of Regents has established six academic colleges for the state university, a Division of Statewide Services and the positions of academic vice president, vice president for research and advanced study, six deans of the academic colleges, and dean of statewide services.

The colleges will be the College of Arts and Letters; the College of Biological Sciences and Renewable Resources; the College of Business, Economics and Public Administration; the College of Earth Sciences and Mineral Industry; the College of Mathematics, Physical Sciences and Engineering; and the College of Social Sciences and Education.

In the May 17-20 meeting, the Board of Regents concurred in the naming by Dr. Wood of deans for the new administrative organization. Those appointed are Dean William Magee, College of Arts and Letters; Dean Hans Jensen, College of Business, Economics and Public Administration; Dean Earl Beistline, College of Earth Sciences and Mineral Industry; Dean Charles Sargent, College of Mathematics, Physical Sciences and Engineering; and Dean Charles Ray, College of Social Sciences and Education. Announcement of the naming of the dean of the College of Biological Sciences and Renewable Resources will be made at a later date.

An Industrial Training Program in Advanced Reactor Engineering

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Introduction

Ten years or more after the end of the Manhattan District, industrial concerns and AEC National Laboratories still were the chief places where formal training in nuclear science and engineering could be obtained.[2] The best known of the available programs was, perhaps, the year's course offered by the Oak Ridge School of Reactor Technology (ORSORT). Recently, however, there has been a massive entrance of universities and colleges into this field. Of 310 educational institutions responding to a questionnaire sent out by the Oak Ridge Institute of Nuclear Studies (ORINS), 141 indicated that they were offering either formal degrees in nuclear engineering and science or at least nuclear options as part of their normal degree programs in science and engineering.[3]

In spite of this substantial increase in educational activity in the nuclear field by the colleges, the number of graduates with nuclear training has not been sufficient to meet all the demands of the nuclear industry. Furthermore many experienced engineers and scientists who received their training in the more conventional branches of engineering are switching to the nuclear field and are in need of specific nuclear engineering training. Finally, B.S. and M.S. graduates in the nuclear field are no exception in their need for additional training if they wish to acquire the ability to analyze and find solutions to difficult engineering problems. While many will choose further graduate work as a means of acquiring this ability, there are others who are more strongly motivated in an atmosphere of industrial activity where engineering problems that require solution are faced daily. For all three reasons the need for industrial courses appears to continue.

In this paper, we describe two advanced reactor design and analysis courses given at the Knolls Atomic Power Laboratory (KAPL). The main function of the laboratory (KAPL), which is operated for the AEC by the General Electric Company, is the development and testing of nuclear reactors for ship propulsion. There has been a continuous need for training programs since this work was first undertaken. In 1959 a reevaluation of the available training programs was made. While there were quite excellent courses available in a number of fields, some sponsored by the General Electric Company and some by nearby colleges, they were not sufficiently specialized to meet the needs of the laboratory. Particularly needed were more men who understood heat-transfer, fluid dy-

[1] Operated for the United States Atomic Energy Commission by the General Electric Company.

[2] There were a few exceptions—for instance, a university program in nuclear engineering was already under way at North Carolina State College in 1950.

[3] Oak Ridge Institute of Nuclear Studies, "Educational Programs and Facilities in Nuclear Science and Engineering," September 1960.

namics, neutron physics, and their interrelationships as applied to reactor design. It was decided that additional training opportunities would be offered in two different ways:

(1) An intensive two-year program for young engineers would be offered along the lines of the last two years of General Electric's three-year Advanced Engineering Program (AEP)[4] dealing in part with fundamentals but oriented particularly toward reactor core-design studies. An integral part of the program would be a series of six-month work assignments in appropriate areas. This Advanced Reactor Engineering Program (AREP) is described at first.

(2) In addition a one-year seminar program would be offered for the benefit of more experienced engineers who had already attained a degree of expertness in some aspect of reactor or nuclear power-plant design but who wished to increase their over-all understanding of reactor technology. This course, The Advanced Nuclear Thermal Engineering Seminar (ANTE) numbers among its members many senior people who in turn may contribute to the teaching in areas of their particular proficiency. ANTE is a problem and design course and is described in the last sections.

Advanced Reactor Engineering Program (AREP)

The purpose of the ARE Program is to meet the laboratory's need for trained manpower. Its basic educational idea is that sound engineering training in industry is best furthered by emphasis on the teaching of fundamentals through application to design problems Four broad objectives are defined to carry out this idea:

(1) The program should achieve a relatively rapid introduction of personnel to the art and science of reactor engineering.

(2) Topics to be stressed should be in the areas of heat transfer and fluid flow, reactor physics, reactor kinetics, and systems study, as well as advanced mechanics and applied mathematics.

(3) Strong emphasis should be placed on ability to solve technical problems. The student should be taught to use simple techniques for obtaining an initial, approximate answer. This initial answer can then be refined by the use of more sophisticated methods.

(4) Finally there should be an emphasis on design or synthesis — on putting the whole thing together. This is essentially an art. It includes not only the ability to interrelate analyses of different aspects but also to recognize which are the critical problems that deserve the greatest effort. It should be made evident that in the end the purpose served by most of the analyses is good design.

AREP is a two-year program, the first and second year being designated as ARE-I and ARE-II, respectively. Students entering this program should already have taken the first year of General Electric's Advanced Engineering program or have other background deemed to be equivalent, such as a master's degree and one or more years of work experience.

Each course runs for 36 weeks. The class meets once a week for four hours of lectures and class discussion. Outside work takes 20 to 25 hours per week. All students work a regular 40-hour week on other engineering work.

During the two-year program the students are given three or sometimes four work assignments in different reactor design and development groups. At the completion of the program, the student, if he does well, may be expected to have several opportunities for permanent placement.

ARE-I and ARE-II each have as course supervisor a senior technical man who

[4] This program has been operated by the General Electric Company for many years. Many of the company's outstanding engineers and managers are graduates of this program.

gives practically all his time to developing and running the course. He works out the details of the year's curriculum, selecting an appropriate sequence of lecturers and giving a fair portion of the course lectures himself in fields in which he is particularly qualified. The remaining lectures are given by guest lecturers of outstanding ability who may be expected to present the most up-to-date material available in their fields. However, the course supervisor has the responsibility for seeing that continuity and sound development of subject-matter are achieved throughout. He selects the text books for the standard parts of the course and prepares extensive supplementary course notes based largely on specific technical material and internal laboratory reports. As a teacher the supervisor has the further primary responsibility for charting the progress of the students and for counseling and assisting them as needed.

Since the course depends in large measure on the problems done by the students each week, one of the most important tasks of the course supervisor is to develop good problems. Although exercises have their obvious uses, particularly in the development of a new subject, so far as possible engineering-type problems related to reactor design are used, where considerable analysis is required and where there may be more than one "answer."

Students are selected on the basis of their past record, an interview, detailed recommendation by their supervisor, and an entrance examination. In the first two classes over 80 per cent of the students either had master's degrees, in most cases with a minor or major in the nuclear field, or they had completed at least the first year of the General Electric Advanced Engineering Program. The remainder, with only bachelor's degrees, had had experience which gave them roughly comparable preparation. The work experience of the students ranged from one to eight years, with varying amounts in the nuclear field.

A student's reasons for embarking on an extensive educational program are usually complex. Opportunity to acquire knowledge and understanding in a new field, as well as ability to contribute effectively to an important engineering project are usually major motivations. In addition, the class is run on a very competitive basis with salary increases reflecting the student's performance both in class and on his rotational work assignments. Finally the greater technical competence resulting from the successful completion of the course results in a certain amount of prestige, the prospect of which in turn, acts as an incentive to perform well on the program.

The Curriculum of the AREP

The curriculum is arranged so that fundamentals are taught through application to reactor design studies and analytical evaluations. The two-year scheme is shown in Table 1. The subjects of mathematics, fluid flow and heat transfer, feedback, and stability studies have obviously wide application outside the field of reactor engineering. Although the field of reactor physics is a little more specialized, its methods are sufficiently broad so that experience in this area will certainly help to develop ability useful in other analytical fields as well. In short, although the curriculum is oriented toward reactor design, a student mastering it will be well prepared to work in other fields as well. This sound basis for versatility is obviously an advantage for the man. It is an advantage for the laboratory as well, for an R and D laboratory must be prepared to cope with new and unforeseen problems. At the same time focus on reactor problems gives the course the unity that corresponds to the unity of reactor technology.

It should be noted that a special effort is made to put to use the mathematics as it is taught, problems being frequently designed to accomplish this. Mathematical topics are introduced in two ways: as part of a continuous course sequence in mathematics; and also as an integral part of non-mathematical topics. For instance, Legendre polynomials are taken up during the discussion of the P_l approximations used in the

solution of the Boltzmann equation in reactor theory; the calculus of variations is reviewed briefly when variational techniques are applied; matrix methods are studied in connection with complex vibration systems and so on.

An integral part of ARE-II is a design problem assigned at the start of the year. It involves the complete design of a reactor core with some minor sketching of the associated power plant. The design problem is worked on throughout the year. The class is divided into a number of design teams and each team works on a different set of design specifications to be met by their design. These specifications are phrased very broadly so that a large part of the problem definition is left to the design team. Work on such a comprehensive problem enables, in fact almost compels, the student to synthesize the material from the rest of the course and to apply it to a reasonably realistic engineering situation. This "group thesis" is then presented in report form at the end of the course.

Student Advisers

Each student in the program chooses as an adviser a senior technical man in

TABLE 1

CURRICULUM FOR THE TWO-YEAR ARE-I AND II PROGRAM*

First Year (ARE-I)

	Units		Units
Advanced Mechanics	8	*Mathematics*	37
Heat Transfer and Fluid Flow	11	Ordinary Differential Equation	(2)
Review of Thermodynamics	(1)	Series Solutions of Diff. Eq.	(3)
Navier-Stokes Equations	(2)	Orthogonal Functions, Sturm-Liouville Systems	(2)
Laminar and Turbulent Flow, Boundary Layer Theory	(2)	Numerical Solutions of Ordinary Differential Equations	(4)
Natural Convection	(1)	Vector Analysis	(2)
Boiling and Condensation	(2)	Matrices, Determinants, Eigenvectors and Eigenvalues	(3)
Conduction	(1)	Partial Differential Equations	(3)
Thermal-Mechanical Stability	(2)	Eq. of Mathematical Physics	(3)
Reactor Physics	16	Green's Functions	(2)
Review of Nuclear Physics	(2)	Integral Equations	(2)
Neutron Diffusion Theory	(2)	Numerical Solutions of Partial Differential Equations	(3)
Neutron Moderation	(3)	Complex Variable Theory	(3)
Few Group Theories	(3)	Calculus of Variations	(2)
Control Rod Theory	(2)	Transform Calculus	(3)
Long-Term Reactivity Changes	(2)		
Reactor Kinetics	(1)		
Introduction to Transport Theory	(1)		
	35		37

Second Year (ARE-II)

	Units		Units
Reactor Physics	34	*Applied Mathematics*	6
Neutron Transport Theory	(6)	Integral Equations	(1)
Neutron Slowing-Down Approx.	(5)	Complex Variable Theory; Appl. to Heat Transfer & Potential Flow	(5)
Variational Methods in Reac. Theo.	(7)	*Reactor Thermal-Hydraulic Design*	12
Fission Product Poisoning	(2)	*Advanced Vibration Theory*	8
Partially Enriched Reactors	(2)	*Reactor Design Problem*	14
Theory of "Burnable Poisons"	(2)		
Unconventional Reactor Control	(2)		
Reactor Stability Analysis; Feedback Control	(8)		
	34		39

* Usually the four-hour weekly class is divided into two sessions and two subjects are taught in parallel. This is only very roughly indicated by the two parallel columns in the table. Thus, one week's work corresponds to two units, making 72 units per year.

the laboratory with whom he feels that he can establish a good personal relationship. Thus he can be assured of someone who will take a personal interest in him, advising him where he might do well to seek work assignments that will be in accord with his interests and of maximum value to him.

The advisers are also of help to the laboratory, not only by helping their charges to make the most of their opportunities, but by being familiar with problems that arise in the course. An adviser often hears about course difficulties before the course supervisor does and he can thus make constructive suggestions for course improvement.

Rotational Work Assignments

The rotational work assignments are considered to be an integral and important part of the program. They serve to acquaint the student with many of the vital engineering problems with which the laboratory is concerned, motivating his interest in the course. They keep him from specializing too early. He has a chance to try himself out in the different fields he is studying and to get additional perspective on how these fields are related. He learns "by doing" in each area.

In selecting assignments, several educational objectives are held in mind. The student is required to take assignments in both reactor physics (sometimes referred to as "nuclear analysis") and core thermal design groups, usually for six months each. He further has to take at least one work assignment in an experimental area. This is felt to be particularly important for men who are being trained in methods of mathematical analysis applicable to design. If a man is going to spend most of his life in analytical work, he will probably profit greatly by spending at least six months at some point early in his career doing experimental work. In general, there appear to be too few men sufficiently skilled in both analysis and experiment to be able to build a bridge between the two. The required experimental assignments therefore represent at least a small move toward correcting this situation. The experimental assignment may be taken in reactor physics (critical assembly experiments), in thermal-hydraulic loop and model testing, or one of the power reactors at the KAPL West Milton Reactor Site. It may last anywhere from four to ten months.

The student is encouraged to look at other possible assignment areas and to take an additional assignment if he wishes, even though it may involve a slight delay in coming off the program beyond the termination of the course work. A favorite area for additional assignments has been in Power Plant Transient Analysis; others have been in Shielding, Mechanical Design, Coolant Technology, and various other Power Plant areas.

Problems and Difficulties of the Program

One of the difficulties that arises is the perennial question of "depth versus breadth." Obviously there should be both. Equally obvious this is not possible in all areas. In addition to special talents and a thorough education, experience is an important ingredient in the making of competent engineers and scientists. There is a definite gain from the combination of work experience and course work, but the pressure of studying while working may become great. However, the problem is recognized and a continuous effort is made to balance the conflicting demands for depth and breadth and to steer some sort of middle course.

Another important problem concerns the best way for the student to invest his after-work time. Since the acquisition of skill in problem solution is a basic objective, the General Electric Advanced Engineering Program tradition of assigning weekly problems that require 20 to 25 hours a week has been followed. But this leaves very little time for free study, so necessary if a subject is to be really understood. The present plan is to continue these weekly problems but with some increased time devoted to the design problem in the second year. This offers opportunity for less specifically directed

work and is a starting point for at least some "free" study. Further steps may be considered later.

A final problem of the AREP is the question of judging its success or failure. The student's judgment regarding the over-all program effectiveness is likely to be more valid several years hence than while he is still immersed in the program. On the other hand, any current difficulties or criticism the students may have are rightly a matter of concern to the course supervisors. A relatively reliable method is needed for judging the long-range effectiveness of the AREP and for providing additional constructive criticism so that the program may be improved. The method now in use is to have a "steering committee" or advisory board, a small group of high-level technical men in the laboratory with whom questions of curriculum content and needs, general policy, and other matters can be discussed. It is a means by which other laboratory members can be kept in touch with what is going on, it serves as a useful sounding board for ideas, and it provides some collective judgment on how the program is succeeding.

The Advanced Nuclear-Thermal Engineering (ANTE) Seminar

This one-year course offers a chance to the more experienced men in the laboratory to broaden their training in the field of reactor engineering. The course is more applied than the AREP and does not attempt to give the same sort of training in fundamentals, though it does not entirely neglect them. It has to be assumed that the men in this program have had broad training in engineering and science before they take the course. (The first year the course was given, more than half the men either had doctor's degrees or were supervisors of technical work or both.) Otherwise, the ground covered is closely related to that given in the two years of AREP. The Nuclear-Thermal Seminar is also more flexible in that certain parts of the course may be omitted by those students already competent in the area in question.

Like ARE-I and II, the course is essentially a problems course, but the problems require only 10 to 12 hours per week instead of 20 to 25, on the average. Most of the men are considerably older and have more demanding work and other obligations and cannot devote as much time to the course as is expected from the younger men. The class meets once a week for three hours. The men remain in their usual jobs, without rotational assignments. Students are selected on the basis of their past record, an interview, and a recommendation by their supervisor.

Although problems are graded, the course is not run on the same sort of competitive basis as ARE-I and II. The men differ greatly in background and experience and their course performance does not directly affect their salaries. Nevertheless there has been a strong motivation on the part of most of them to keep up with the immense amount of ground that is covered in a single year.

An important objective of the seminar is to enable the students to synthesize satisfactory designs from a knowledge of the pertinent fields, or at least to give them a basis from which they can proceed to do this with increasing skill. The topics covered in the course are shown in Table 2. A design problem, assigned early in the course and to which more and more time is given as the course proceeds, deals with an advanced type of reactor that presents many novel difficulties, including transient and instability problems. Many of the reactor problems are not yet adequately understood from a fundamental point of view and the best methods available for dealing with them are very often based on purely or partly empirical data with no really adequate theory to support them. But to make sure that the students have a basis for thinking about the limitations of the empirical design approaches in use, there is enough emphasis on fundamentals in the course to encourage and make possible future methods development.

The problems recognized in connection with the AREP take a slightly different form here. Proper student motivation is harder to achieve in ANTE than in

TABLE 2

CURRICULUM FOR THE ADVANCED NUCLEAR-THERMAL ENGINEERING SEMINAR*

	Units		Units
Reactor & Power Pl. Interrelation	3	*Review of Applied Mathematics*	5
Fundamentals of Heat Transfer	10	*Reactor Physics*	25
Review of Thermodynamics	(1)	Review of Nuclear Physics	(2)
Boiling and Condensation	(3)	Neutron Diffusion Theory	(2)
Lam. & Turb. Boundary Layers	(2)	Neutron Moderation	(3)
Natural Convection	(1)	Bare Reactor Theory	(1)
Two-Phase Flow	(1)	Few Group Theories	(4)
Conduction	(2)	Control Rod Theory	(2)
Reactor Thermal-Hydraulic Design	6	Long-Term Reactivity Changes	(3)
Hydraulic Circuits	(1)	Reactor Kinetics	(1)
Thermal Criteria	(1)	Introduction to Transport Theory	(2)
Hot Channel Factors	(1)	Perturbation Theory	(2)
S.S. & Transient Thermal Design	(3)	Special Nuclear Design Problem	(3)
Fundamental Feedback Theory	9	*Reactor Design Problem*	14
	28		44

* Two units per week for 36 weeks (72 units total).

AREP. The difficulty is that in many cases the men are under so much pressure with their regular work that they cannot give the necessary time on a consistent basis. Many have also gotten out of the habit of intensive study, a habit which most of the younger men selected for the AREP do have. Recognition for performance, salary and otherwise, is based entirely on their other work and not on work in the course. In view of this, it is rather remarkable how persistently, on the whole, the members of this class have worked. However, the difficulty is not easy to overcome, and in both years that the course has been given a considerable percentage of the students have had to drop out. It has been necessary to insist that there be no auditors and that only those attend who find it possible to do all course problems.

The problem of "depth versus breadth" in some ways is even more pronounced here than in AREP because an attempt is made to cover more ground in less time. However, this is more than balanced by the fact that most of the men in this course have already specialized before taking the class, and they will presumably, in most cases, continue to develop those specialties. What they gain, primarily, is a broad understanding of those technical areas that are intimately contiguous to their own.

Finally, we have sought the same solution to the problem of evaluation as for AREP. The steering committee members can be consulted when needed, either individually or collectively, and they have been most helpful both in their suggestions relative to the curriculum and on various policy matters from time to time.

Conclusion

Although final conclusions about these courses cannot be drawn this early, they have already shown that they are serving a useful purpose. There was considerable competition for the first graduates of the two-year AREP. This is hardly surprising when one considers the alternative the project manager usually has of recruiting men from outside the laboratory who are not only untried, but not trained specifically in relation to the type of work to be done.

The ANTE Seminar has provided a means for giving additional training to older men who seriously wanted it, and a surprisingly large number of men have taken advantage of it.

A significant two-pronged training program has been added to the laboratory. The fact that the classes have been kept in close touch with the engineering and development work that is going on has been important. There seems every

reason to expect that the courses are having and will have a significant effect in the laboratory. Most of the older men who desire the training offered by ANTE soon will have had it. But the need for training new men will presumably continue and the AREP is already proving attractive to students and of value to the laboratory.

The authors wish to acknowledge the important parts played by Messrs. R. L. Mathews and F. B. Newkirk who were successively supervisors of ARE-I. Their development of an effective curriculum and establishment of a high standard of performance for the first year was of vital importance to the success of the program. We would also like to mention two vital factors underlying the whole program namely, the constructively watchful eye that Dr. H. J. Plumley has kept on the program almost from the beginning and the initial energetic action and support by the Naval Reactor's Branch of the AEC and the laboratory's General Manager, Dr. B. H. Caldwell.

APPLICATIONS FOR GRADUATE AWARDS INVITED BY NATIONAL SCIENCE FOUNDATION

Applications will be accepted through January 5, 1962, for National Science Foundation Graduate Fellowships for advanced study in the sciences.

Fellowships will be awarded in the mathematical, physical, medical, biological and engineering sciences, and anthropology, geography, psychology, sociology, and the history and philosophy of science. Also included are interdisciplinary fields which are comprised of overlapping fields among two or more sciences such as oceanography, meteorology and geochemistry.

To be eligible for graduate fellowships, applicants must be citizens or nationals of the United States and have demonstrated ability and special aptitude for advanced training in the sciences.

Fellows will be selected on the basis of ability as attested by letters of recommendation, academic records and other appropriate evidence of potential ability for scientific study or work. Applicants for graduate fellowships are required to take the Graduate Record Examinations. Their qualifications will be evaluated by panels of scientists appointed by the National Academy of Sciences—National Research Council. Final selection of Fellows will be made by the National Science Foundation.

Stipends for National Science Foundation Graduate Fellowships vary with the academic status of the Fellows. Students entering graduate school for the first time or those who have had less than one year of graduate study are considered First-Year Fellows and will receive annual stipends of $1800. Fellows who need no more than one calendar year of training to complete the requirements for the doctoral degree will receive annual stipends at the rate of $2200. Fellows between these two groups will receive stipends at the rate of $2000 annually. For married Fellows a dependency allowance of $500 per annum for the spouse and a further $500 for each dependent child will normally be available. Tuition, laboratory fees and limited travel allowances will also be available.

An announcement describing these fellowships is available from the National Science Foundation, Washington 25, D. C.

Application material for National Science Foundation Graduate Fellowships may be obtained from the Fellowship Office, National Academy of Sciences—National Research Council, 2101 Constitution Avenue, N.W., Washington 25, D. C. Awards will be announced on March 15, 1962.

Sincerely yours,
CLYDE C. HALL,
Public Information Officer

Development of a Modern Laboratory Sequence In Mechanical Engineering Instruction

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The Mechanical Engineering Department at The University of Detroit, aware of the need for changes to suit the requirements of a modern engineering profession, found it desirable to work out a revision and development of its curriculum. It soon became obvious that major changes had to be made in the teaching approach in the laboratory. It was decided that all then current laboratory procedures and teaching devices should be scrapped and a new start made. Since these were well developed and associated with specific objectives for particular courses, this meant a departmental revolution. Both faculty and students were directly involved. There was need for considerable explanation of the new objectives and there have been many instances of resistance to the change.

The development work on this project started in 1953. Nothing about it has been written until now, since it was necessary to get some evidence concerning the value of the approach after the students had a chance to develop further, even after graduation. The indications are that the results have been good and the experiences worth sharing.

Objectives

The objectives of this laboratory program are manifold but the prime objective is to teach an engineering approach to real problems. The lecture and the laboratory are treated as separate parts of the curriculum. It is intended that each be utilized to its full extent to educate the students to the highest degree possible. Of course, the laboratory work is used to bolster the theoretical classroom work, but it is directed at developing the student rather than a particular experimental phenomenon.

The laboratory is an ideal place to develop student initiative and responsibility. It is an excellent place to develop the art of communication. These items are all interrelated and may be developed at the same time. For instance, by scrapping all experiment sheets, procedure outlines and report forms, the teacher can put the student in the position where he must use his initiative in a responsible manner to obtain anything to report. Furthermore, much more factual material can be covered if the experiment is all laid out ahead of time. However, this Mechanical Engineering Department concludes that the student does not learn as much in specific experimentation. He may be amazed at the results and interested in the phenomena but his progress in real education is relatively small.

A student completing a series of laboratory courses of the type referred to here may know less about specific items than one who has followed preplanned experimental procedures, but specific experimentation may actually be a *deterrent to the development* of the student. Too much emphasis is placed on specific items and factual information. These are of little value when he has to approach a new problem. Very likely the instrumentation used would be outmoded before he was graduated and specific applications would also be outmoded. Thus, there is relatively little value in specific application.

The student must be taught how to approach problems which are new to him and which he may believe are unsolvable. However, if he has the experience of being guided by the instructor to a reasonable solution he will learn the general approach and will be in a much better position to attack new problems. The student should be reminded constantly that if the problem has been solved many times before it is not engineering. The engineer's task is to solve new problems. The student can be taught the accuracy of instruments and measurements without spending valuable time in refining a technique. Most technicians will be much more adept with actual instruments than the professional engineer needs to be. Thus, accuracy should be taught as an educational item, not a technique of manipulation.

The objectives of this laboratory program can be summarized as:

1. Develop the student in
   a. Initiative,
   b. Responsibility,
   c. Art of communication,
   d. Engineering judgment.
2. Teaching measurement.
3. Teaching the engineering method of analysis.

It must be borne in mind at all times that since the laboratory program entails the above objectives, it is a very important part of the curriculum and cannot be relegated to the young and inexperienced teachers. Teaching a laboratory course such as this is a challenge for any good teacher.

General Description

The University of Detroit College of Engineering operates on the cooperative plan. The length of the academic term is approximately twelve weeks. The student does not start on the cooperative plan until he reaches the junior year. Then because he has a cooperative work position for at least a calendar year before graduation, he must be in school for six terms in order to complete the last two academic years.

The laboratory courses are planned as a sequence and offered as follows: two courses in the junior year (one in each semester), one course in the pre-senior year, thesis in the senior year.

An undergraduate thesis is required of each student and is accomplished in the two semesters of the senior year. Because of the nature of the work, the thesis project provides a very good proving ground for the laboratory sequence. These laboratory courses are designed for one hour of lecture and three hours of application each week. Laboratory sections should be as small as possible. Experience indicates that the following sizes are reasonable:

First course — 12 students per section,
Individual sub-sections to be formed as required.

Second course — 12 students per section,
Individual sub-sections to be formed as required.

Third course — 12 students per section,
Subdivided into groups of 4.

Thesis — Individual problems usually —
Pairs of students on a thesis project permissible at the discretion of the thesis adviser.
More than two students for a thesis project is usually discouraged.

Since the laboratory courses are planned as a sequence, it is important for the student to appreciate that he is working in a sequence. The laboratory plan is explained to the student in the first course in the junior year. Then the plan is re-explained and further developed in each semester as the student progresses.

In the first course in the junior year, the instructor works closely with the student to accelerate the development of his initiative and responsibility. In the second course the instructor deliberately withdraws from the close contacts with the student and acts somewhat as a project supervisor who has detailed knowledge of what is going on, but who is not directly responsible for the detail work. In the third semester the instructor is further withdrawn from contact with the student so that he acts as an adviser. At this stage he makes the student act as independently as possible.

In the thesis project, the adviser is in a position to assume his proper role as an adviser since the student has been developed in initiative, responsibility and the art of communication. Many of the minor and detailed duties ordinarily required of thesis advisers in undergraduate work are unnecessary. The student is able to carry out a much more sophisticated thesis project.

Description of Equipment and Instruments

The equipment used must be very flexible and adaptable to a large number of problems. The concept of a facility must be developed. Routine test procedures, power test codes, performance codes and the like cannot be used to good advantage in the laboratory sequence described here. Practically all large-scale equipment has been found too cumbersome and not adaptable for this type of work. Much work has been done on small equipment adaptable to many different problems. Emphasis has been placed on making accurate and valid measurements and evaluations rather than on what the values are. The educational value rests in being able to determine a quantity *as it is* regardless of the number value, or the reasonableness of that value in an engineering economy study.

Before a proper instrument can be chosen for a particular purpose, it is necessary to determine what quantity is to be measured and the accuracy with which it is to be measured. For the purpose of education, most recording instruments are not very valuable. It is not reasonable to attempt to accumulate a collection of all instruments which exist for use in the engineering field. Even if one had them there would be no time to teach all about each specific instrument. In many engineering projects the measurements which must be made require instruments which do not exist. The greatest educational value results from *teaching about instruments and instrumentation*, rather than attempting to describe and utilize a multiplicity of instruments. Instruments and instrumentation should be treated as a part of the measurement problem and the *emphasis should be placed on measurement* rather than on the instrument which does the measuring. The student, properly educated in measurement and instrumentation, will come to appreciate the proper position of the instrument in his problem. He may even devise his own instruments if he cannot secure ready-built devices. Since this is true, the laboratory work, particularly in the earlier courses should be based on the use of elementary instruments with relatively little concern for the highly refined models until after the student has learned measurement and instrumentation.

After the student is sufficiently educated in this area there will be ample opportunity to utilize some of the modern high-speed and involved instruments. Recording instruments may be used after the student comes to understand what the instrument is doing and what it is recording, so that the instrument and the recorder actually act as tools in the project. Such things as accuracy, response, interference by the instrument with the item being measured, and other very important basic items can be taught much more satisfactorily by the use of the elementary instruments.

The student must be placed in the position where he specifies the instrument necessary to make the measurement, based on what is required. If the student makes a measurement with an instrument specified by the instructor, the educational benefit is questionable. The student may feel that he is learning something; however, he will not have learned much, since he did not do the thinking required in the choice of the instrument and its application.

When the teacher attempts to *teach the art of measurement and the associated instrumentation* instead of *demonstrating the application of a particular instrument* in a specific problem, he will find that the number of things he can do is relatively limited. The number of instruments available is certainly outside the range which can be handled and very likely not adequate or suitable for the solution of many engineering problems.

It was concluded that it was not reasonable to attempt to teach instruments as such. Based on this the department has adopted the concept of teaching *measurements* in the solution of engineering problems as a very important part of our laboratory objectives.

The student may look skeptically at the using of ordinary instruments in the earlier laboratory courses. He may feel that he is not being properly treated unless he has some elaborate instruments with which to work in the first semester laboratory course. It is part of his education to learn that these more complicated instruments do not lend themselves as readily to the educational venture of teaching measurement and good laboratory procedures as the more prosaic and ordinary instruments.

Course Description

The first course of the laboratory sequence includes one hour of lecture and discussion and one three-hour period of experimental laboratory work per week. The first lecture hour of this course is spent familiarizing the student with the laboratory sequence, its general objectives and attitudes. The student is introduced to the fact that he will be expected to plan his own work and think for himself. He is informed that there will be a deliberate attempt to avoid predetermined experimental answers. He is made acquainted with the idea that he will be expected to analyze the problem, obtain results and draw conclusions from the results. He is told that, since the job he will be doing has never been done before, the results and conclusions might be in conflict with the instructor's ideas, but he is expected to work at the solution of the problem at hand and not concentrate on trying to obtain data which he thinks will please the instructor.

Every effort is made to convince the student that the instructor wishes him to do his own thinking and will credit him with having done a good job even though the results found appear contrary to what the instructor thinks they should be. The student is informed that he will be responsible for getting his assignment done on time and in a reasonable manner. Since there is no predetermined answer to the problem, the student must rely upon the conclusions drawn from the results obtained and he must have the courage to report what he finds. In some cases the conclusions may seem peculiar. If they are consistent with the results, the student is expected to offer reasonable explanation of why this is so.

The objective of the first-semester laboratory is measurement in its general sense. This involves data, data taking, and validity of data. It also involves instrumentation and the calibration of instruments to obtain correct data. The instructor attempts to make the student self-reliant in measurement. He discusses problems having to do with data, data taking, need for calibration and the problems involved in locating instruments to get proper data. He deliberately keeps away from the assigned problems, leaving that for the student to work out.

Problems assigned in this laboratory are planned around general topics such as pressure measurement, temperature measurement and speed measurement. Specific instructions are kept to a minimum.

The student is soon brought to the realization that he must use instruments to get data. He comes to realize that the instrument indicates some quantity but that quantity is useless unless properly interpreted. He finds out that the *location* of an instrument is particularly important. He learns about the *lack of equilibrium*, *transients*, and the difficulty of obtaining *representative data*. He learns that there are a number of ways of measuring the same quantity and he is put in a position to learn that the means of measuring a particular quantity *may not exist*. He should not be allowed to make a measurement until he has a reason for making it.

The uninitiated student is usually impatient to get into the laboratory to make measurements. He is likely to take much more data than he needs. He is prone to take irrelevant data with the hope that possibly some of it will be of use when later he tries to draw a conclusion from the results. Since the student is given a problem with no procedure

sheet, he faces the need to determine what he is to do *before* he goes into the laboratory. He finds that he must choose his instruments, locate them properly and know the significance of the indication of the instruments.

When a student draws equipment from the instrument room, he is required to specify the type of equipment, the range he desires and other pertinent information. From the foregoing discussion, it can be seen that there are many opportunities to make the student realize he must be responsible for his conclusions and his actions. If the teacher doesn't do things for him, the student will have to use his own initiative. At the outset, he may work harder trying to find ways not to take the initiative than he would if he attempted to take it. It isn't long before he comes to realize the value.

The instructor must gain the confidence of the student and convince him that he will be treated fairly with respect to grades. The teacher cannot expect the student to take the initiative and work in an unknown field without making mistakes. Therefore, the teacher will have to be tolerant of mistakes and ready to commend the student when he does a good job. The teacher and student will experience the necessity for treating grades in a much broader manner than a simple averaging of numbers placed on reports and other assignment sheets.

In the first-semester laboratory considerable emphasis is placed on the art of communication. A student is required to prepare a report with rigid requirements. He is given specific instructions about these requirements and is expected to follow them. One of the instructions is that the report must be in good English. No credit is given for using good English since it is *assumed* that the student should be capable of this. If the English is not good, the report is considered not acceptable and is returned to the student.

The student is given specific instructions concerning graphs. He is told that since the presentation of data graphically is so important in engineering and is such a valuable device, he will be expected to present data in this form as much as possible and to be particularly careful about the preparation of it.

If a report is not properly prepared due to technical errors, graphical presentation, or English the report is returned to the student marked "not acceptable," with indications from the instructor about the difficulties. The student is expected to rework the report and turn it in with the next report. If after being reworked, the report it still not acceptable, it is given a failure grade. If it is acceptable it is graded on its merits at that time and may turn out to be an "A" or excellent grade. No more reworking is permitted.

The faculty recognizes that the student will spend too much time in the preparation of the first report. Experience indicates that he will cut that time by as much as 60 per cent if he progresses properly during the first semester. The faculty believes that in many cases the specific experiment approach leads to too much time spent in preparing reports which include masses of data of the repetitive nature requiring inordinate amounts of student time for a relatively small return in education. If initiative, responsibility and the art of communication are to be taught effectively, it is necessary to place the student in the position where he has to choose between spending too much time or using his initiative and responsibility to expedite matters. Since the intent of this approach is not technical alone but concerns the whole objective of engineering education, it is believed that this time is well spent. Many students have indicated that although they felt at the beginning of the semester that this approach was a burden, before the end of the semester they had progressed to the point that it was not burdensome.

There is no need to repeat these report requirements once the educational objectives are obtained. Therefore, in succeeding courses of the sequence the *report requirements are cut to a minimum* with the exception of the thesis report, which of course must be a complete and formal presentation.

Near the end of the first semester, the student is introduced to the concept of engineering analysis. Although the objective of the first-semester laboratory course is *measurement* in the general sense, the concept of the need for engineering analysis in the solution of real problems is introduced to prepare the way for the next semester's work.

At the end of the semester the student is given a laboratory final examination one-half to one hour in duration. In this examination he is required to attempt a real problem in which he will have the opportunity to use much of the general thinking developed during the semester. *No specific items or questions referring to work done during the semester are introduced into the final examination.* The objective of the examination is to provide the student with a summary picture of the whole semester and to give some indication of how the student progressed during the semester. Here again the teacher must be very careful to explain the nature and objectives of the examination to the students.

Engineering Analysis

The objective of the second course is engineering analysis. The first hour of the course is used to recall for the student the concepts and objectives of the total laboratory sequence and to show the particular position of the second course. Engineering analysis is described and discussed in some detail. The student is reminded of the need for him to use his initiative in the problem of engineering analysis. He is reminded of the work done in the first laboratory course where the objective was measurement. The experiences of the first semester laboratory course were broad enough so that he should have obtained a fundamental concept of measurement. He is told that it will be presumed that he knows about measurement, data, data taking, instrumentation, and the art of communication and that he will be held responsible for applying his knowledge in those areas in the second semester now at hand.

All of these items are part of the problem. The instructor should spend relatively little time on them. He should concentrate on the particular objective of teaching engineering analysis. Because of the nature of the problem and the teaching objective, it is necessary to have a new problem each time the laboratory is taught. Of course, there are many problems potentially possible in a particular area of work. It will challenge the faculty to seek them out and adapt them to the particular program. The repetitive use of a problem, even though it is excellent, diminishes the value to the student. Human nature tends to type and classify things. The student is particularly adept at this. He is also very solicitous of the other students' welfare and is too willing to do a favor by indicating the keys to the solution. Since the real value from an educational viewpoint rests in the student, himself, finding those keys, it is important that the keys be not available except through his own thought processes.

The best way of insuring this is for the faculty to assign a different problem each time. This puts a burden on the faculty. However, the results are well worth the effort and the duties are not overly burdensome with the type of cooperative faculty with which most of our engineering colleges are blessed.

The problems for use in this second-semester laboratory should be relatively limited in scope. At this stage of development the student does not understand engineering analysis. A complicated problem would leave him quite far afield. The problem should be of a nature which would prevent its being typed. Also, it should be such a problem that the student cannot find a test code or a procedure concerning it in the literature.

The problem does not necessarily have to be in an area in which the student has had specific study. In fact it is good to use a problem which may involve a theoretical area not yet covered by the student. Most of the scientific principles were introduced in the basic science courses. The student stands to benefit considerably if he is called on to do some thinking in an area not yet covered in the engineering sciences. Naturally, this has to be approached with

considerable judgment. Experienced faculty members should know how far they can go in a matter such as this. The student reaction usually is "but I haven't studied that theory." At this time it is reasonable to point out to him that practically every engineering assignment involves a considerable amount of theory never actually covered by the engineer in a formal classroom. The experienced professional man certainly does not lean entirely on facts which were learned in the classroom but uses a process of orderly thought to arrive at a reasonable solution to the problem.

The problems should lend themselves to engineering analysis and ideally would not be restricted to single value answers. The better problems should be of the type in which the student would seek an *optimum value* rather than a highest value or a single value answer. There are many opportunities here to teach very important fundamental engineering concepts such as rates of change and lack of equilibrium. A host of other very important items enter into the problem solution in a normal and natural manner.

In the actual prosecution of the work, the instructor and the student must keep in mind that the objective for this semester is *engineering analysis*. A written discussion of the general concepts of engineering analysis is given to the student and he is asked to consult the literature about this topic. The student is told that, although there may be many approaches to the solution of a problem, the engineering profession has over the years developed a very good method of analyzing problems using ordered thought processes based heavily on mathematics and the sciences. It is further pointed out that the engineering method is not acquired by heredity but must be learned. Since this student has elected to be a professional engineer, it seems rather obvious that he must learn to think like and to develop the attitude of the professional engineer.

The instructor introduces the problem for the course in such terms that it is not completely defined: for instance, "Find the quantity of flow through a nozzle." At first the student is quite well satisfied with the statement of the problem but after he studies it he finds that quantity could mean mass rate, or volume of flow, or many other things and he comes to realize that the problem, as introduced, is not solvable. He learns that it is necessary to know what the problem *is* before one can solve it. The student is then required to define the problem exactly, including the limits.

It takes a considerable effort on the part of the instructor to *lead* the student to the point where he can define the problem adequately. This is a very important part of the semester's work. The approach used is to require the student to attack the problem and then have the instructor constructively criticize his result and teach him how he might have gone about it to do better.

At this state of development it is not necessary to require a formal report each week. The instructor should require a very brief report on the particular part of the analysis approached that week. In this way the emphasis can be kept on the actual work of learning about engineering analysis. Important time will not be wasted in report writing.

After the problem has been defined, the student is led through the analysis of the problem by the hard route of requiring him to do the *best he can* each week and then have the instructor criticize his work and show him how he might have done much better. All this time, of course, the student is very impatient to get into the laboratory to take data. He finds that he doesn't know what data to take nor what instruments to use in getting it. He must spend more time in analyzing the problem before actually getting into the laboratory. Eventually the student arrives at the position where he can take data. He next finds that the actual data taking is a relatively small part of the engineering analysis. He comes to realize that he must have a pretty good picture of the problem before he goes into the laboratory to get data. Then he must do considerable analysis of these before he can analyze the results and draw the conclusion which should be the answer to his problem.

At the end of the course a relatively formal report is required of each student. Much of this report can be and in many cases is prepared by the student as he progresses through the course. Relatively little time should be spent in the preparation of the report since it is not an objective of this course to teach the art of communication. It is necessary to require a formal report to develop in the student the art of communicating that which he knows.

By the end of the course a student will have had sufficient experience so that he should be able to picture the engineering method of analysis well enough to solve a problem of his own.

Due to the nature of the work the instructor will find that he has relatively little numerical data on which to base his final grades. It will be necessary for him to grade using considerable care based on his observations of progress on the part of the students during the semester. Since the students are put into the position of making mistakes from which they can learn, the grades must be based on progress made.

The third course is composed of one hour of lecture and three hours of laboratory time. The students are divided into groups of three or four. A problem is assigned to each group by the instructor. The problems are chosen in such a manner that the student group will have the opportunity to apply the knowledge gained in the two previous courses. No specific instructions concerning the solution of the problem or the approach to the problem are given. The work of the two previous laboratory courses is reviewed and summarized before the problem is assigned. The instructor makes himself available to the student when advice or guidance is necessary.

The instructor will answer no questions which are designed to do the thinking for the student. If the student has made a real attempt and finds that he needs help, he can get assistance from the instructor. In general it is expected that he will apply what he has learned.

During the course the student is expected to report his progress each week. The instructor has the option of requiring a written progress report which is quite brief and likely in letter form or an oral presentation by a student before the laboratory class. The oral presentation gives the student a much needed opportunity to speak before a group. It also requires him to think on his feet as questions are posed by his fellow students and the instructor. At the end of the semester a formal report is required of each group.

In this course the student has the opportunity to mature rapidly, because the instructor is withdrawn to a considerable extent. Since this is the first time the student is essentially on his own, the instructor must actually keep a rather close contact with the student's progress and be ready to help him if he gets lost. At this point the student can get lost quite easily. The instructor must be keenly aware of the differences between getting lost because of a lack of effort or initiative and getting into a nonproductive situation. The instructor must have an intimate picture of the progress of each group and the individual within that group in order to guide properly. It may look to the uninitiated as though the teacher is not doing very much since he is holding the student responsible for the prosecution of the project. In actuality he is carrying on a full-time teaching effort.

Thesis Project

An undergraduate thesis is required of all graduates. This project is carried on throughout the senior year. The requirements of a thesis project are such that it provides a good proving ground to demonstrate the effectiveness of the laboratory sequence to date. The thesis advisers are in a good position to evaluate the ability of the student. Some thesis advisers had experience prior to the time when this laboratory sequence was initiated in 1953. They are in a position to evaluate the effectiveness of this program. The thesis advisers who had experience in both laboratory programs believe that the students educated in the present laboratory sequence are much better prepared than those educated un-

der the more specific laboratory approach used before 1953. Present seniors approach the laboratory as more mature people. They also do a much better job in communicating both in writing and orally. They use more initiative and form more responsible conclusions.

Financial Considerations

Such a laboratory sequence can be supported on a moderate equipment budget. The type of equipment needed is relatively small in size and low in cost. Much of the success of the laboratory sequence depends upon the ingenuity of the faculty rather than upon the cost of the equipment. Instruments for the earlier courses can be ordinary items of low cost. However, the kind of instruments required later in the laboratory sequence are costly. It is reasonable to say that the total equipment costs for the laboratory sequence should be relatively low.

Teaching Loads

Because of the nature of the work done in this laboratory sequence a close relationship is necessary between the student and the faculty. Laboratory sections must be smaller. This results in increased teaching load. Over the whole sequence it is estimated that the teaching load has been increased by at least 50 per cent as compared to the experience using the specific experiment approach. This may be considered as a very serious obstacle but the Mechanical Engineering Department feels that it is a good investment, particularly in view of the gain made by eliminating time-consuming laboratory work which is too specific in nature.

General Observations

There are numerous difficulties involved in carrying on any worthwhile endeavor. These depend upon the nature of the project and how it is organized. A few which seem quite typical of this endeavor are mentioned here. Because there is need for a large number of suitable problems, the faculty is constantly challenged to supply them. This is a project for the whole faculty and not for one or two members. If the faculty members get a project such as this started and then fail to supply new problems, the value of the laboratory sequence probably will become less than if specific experimentation is used. Before such a laboratory sequence is initiated the faculty should be willing to assume a continuing effort. The job will not be done by planning the courses for the first group of students.

In the correction of reports, the faculty assumes a more demanding effort. Since the plan of the laboratory sequence is a continuous development, the student must prepare the report and the instructor read it and correct it before the next laboratory meeting. This will likely mean that the teacher will have two days in which to read and grade the reports and prepare himself for the next laboratory meeting which should be based on the progress shown in the reports just graded.

The student will have less flexibility in a plan such as this. However, when the student and the teacher work together the results can be very good. The experience here has been quite good in this respect. Both faculty and students, recognizing the values obtainable, have cooperated very well. There are few exceptions but these are regarded as statistically unfortunate incidents.

The faculty was quite willing to assume the difficulties and the change. The students, recognizing the conviction of the faculty and the possibility of a more beneficial approach, accepted the challenge and cooperated in a very satisfactory manner. They cooperated in such a way as to indicate considerable interest in the laboratory sequence.

Another way in which the faculty is challenged is the fact that all the work carried out in the laboratory is essentially new, being a first-time effort. There are no procedure sheets. The faculty must act in a very flexible manner. It is possible to learn the routine in a specific-experiment type of laboratory. When the routine is eliminated the teacher is faced with a considerably bigger problem. Innumerable situations may arise and some of them are almost unexplainable at the moment. If the teacher is constantly

alert, he can wring real educational value out of each of the problems which arise. Of course, the students and the teacher together cannot arrive always at a reasonable solution of the problem. Even here the teacher can derive a benefit for the student by pointing out the limitations of the approach to problems. Since these incidental problems do not prevent the attainment of a reasonable solution to the semester project, the student gains a very important educational benefit. The teacher finds it a satisfying experience also. Although the particular experience may never be repeated, it is quite certain that there'll always be enough of these occurrences to make it worthwhile.

Results

The results obtained in this laboratory sequence are very satisfactory. Faculty members, particularly thesis advisers, have noted a considerable change for the better since the students who have experienced this laboratory sequence reached the senior year. The goal of making the students more responsible and capable of using initiative was attained in a higher degree than would be possible with the specific experimentation approach in the laboratory. If the student is required to use initiative in the laboratory, the results are not confined to the laboratory. They pervade his whole experience.

Surveys of seniors indicate the students at graduation time feel that, although the laboratory work was more demanding than it would otherwise have been, it was good for them. Therefore, they have been in favor of it. Informal questioning of some employers of graduates who have experienced this laboratory sequence indicates very satisfactory results. Informal questioning of many graduates concerning their reactions to the laboratory sequence with respect to the job or graduate school indicates very satisfactory thinking. The faculty are quite well satisfied with the results. On the basis of results observed, they are convinced that this type of approach to the laboratory teaching is superior to the specific experimentation type in the development of a professional engineer. They will continue to teach and develop the project laboratory sequence.

Recommendations

It is recommended that other schools consider very seriously the possibility of adopting an approach in teaching laboratory other than the specific experimentation type. The project-type laboratory work carried on in a sequence of courses is a promising solution. It is hoped that other faculties have experiences to offer so that the engineering teaching profession can utilize laboratory time to the best possible advantage for the students' growth.

ENGINEERING SCIENCE AT RENSSELAER

Establishment of an engineering science curriculum at Rensselaer effective in September has been announced by Dr. Clayton O. Dohrenwend, vice-president and provost.

The first three years of the program provide courses in basic science, mathematics and engineering science that place greater emphasis on the mathematical and analytical approach than is true of most other engineering curricula. In his senior year, the student is encouraged to elect a sequence of courses either of a physics-oriented nature or chemistry-oriented nature to suit his personal interests and objectives.

While the new curriculum emphasizes basic science and engineering science, it does so in an engineering frame of reference. There are included three courses in engineering laboratory. Also, the senior year requires courses in analysis and synthesis of engineering systems and encourages electives that have similar objectives. It requires, as do all engineering programs at the Institute, considerable study in the area of humanities and social science.

The Trends in Engineering Curricula and Their Effect on Requirements in Mathematics

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I should like to explore, in a very informal manner, the general question as to the relationship between the long-term trends taking place in engineering education and the problem at hand. There is an extremely important correlation in this regard, because in the last twenty years engineering education has been undergoing a revolution. This revolution has a very strong correlation with developments in mathematics—certainly in applied mathematics.

If you look at the task of engineering education and the fundamental objective of the engineering curriculum, you find that the present objective is quite different from that of thirty years ago. Formerly, the general and, without question, accepted objective of an engineering curriculum was the systematic preparation of the student for immediate entrance into the current practice of engineering. The student was supposed to know the mathematics and physics required as an essential background for those methods of engineering analysis, design, and test which he would be called upon to use immediately upon his going out into practice. Today, many of our engineers who graduate from our four-year curricula are still being trained with this as a significant aspect of their training. However, the current objective, and the one which is by and large accepted by the profession in engineering education, is that the student is to be prepared comprehensively, with emphasis on fundamentals, so that he will ultimately be in a position to develop, as an engineer, new systems, new processes, and new devices.

Now you notice the difference in emphasis. In one case I emphasized entrance into current practice, and in the other I've emphasized the ultimate ability to develop. In other words we have shifted our emphasis in engineering education from operations to development. I am using the word "development" in a little broader sense than the usual R and D concept because it includes things which are concerned with the development of new products—the industrial development activities which, from the engineering standpoint, aren't really research but certainly are not operations or current practice. The problems of design as a result of this shift in objective, and again I use "design" in a fairly broad sense, are those which are not so much based on current standard practice, or past practice, but are rather those based on application of broad principles. Let us consider an example. You have the problem of a design of a mechanical power transmission system. This is the sort of problem which today in large part you can put on a computer; you don't need a well-trained engineer to do all of this job. So, a lot of things which used to be done by engineers, which were based on standard practice and which the engineer had to be trained to do, will no longer require the same type of extensive training. The design

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job still remains, but it is now one where you have no complete idea what knowledge you're going to have to use. The probability is that if it's an engineering job of any consequence it's not going to be one which follows standard practice except in a somewhat incidental way. More of the emphasis will be on bringing in new physical concepts and new modes of analysis.

Another consequence of this shift in objectives is that there is a much greater degree of emphasis on systematic and really comprehensive analysis—analysis both for its own sake, the use of what we call mathematical models, and also the very critical analysis of test information. The engineer used to rely very strongly on test results which enabled him to see if the device really worked. Today, our test results in engineering development and engineering design are more intermediate; you get the test results and then you do almost as much analysis on the test results as you do on a mathematical model that you might use. This gives us a great deal more power in developing new things than we formerly had.

There is a very substantial de-emphasis, insofar as the engineering curriculum is concerned, on routine techniques. The engineer formerly had to be a good mechanic if he was a mechanical engineer. We're all very familiar with shop practice courses which used to be standard. I have been in many schools, even in the last fifteen years, where the students were being taught to use forging equipment, the sort of thing, almost, that a blacksmith would use. This has been changed very substantially.

Even such areas as surveying are being changed. We do not now talk about surveying; we talk about photogrammetry. In this, we're making a shift which has some strong mathematical overtones. Drafting is entirely changed from what it used to be. There are a few schools which have no drafting requirements in their engineering curriculum, and it is accepted. Furthermore, there are very few of the engineering schools whose drafting course has not been tremendously changed, and in very few cases do you have any of the emphasis on precision, skill, and pen and ink drawing that you used to have.

Another major change is the introduction of what we call engineering science, or applied science as you may wish to put it, as a major aspect of the engineering curriculum. And then last, as a major consequence of this change in objective, is the shift in emphasis towards graduate work in engineering.

Thirty years ago, there were very few graduate students in engineering. The number of doctoral programs in engineering in 1930 could be counted on the fingers of one hand. Today we all know the change that has taken place, and the evidence is clear that graduate work in engineering will become even more important in the future.

We can look forward to further trends in this direction. The whole area of engineering operation as distinct from engineering development and this is an area which 30 or 40 years ago the majority of engineers went into, is actually being shifted now to the student who is the graduate of the technical institute. This is a trend which is coming about probably more rapidly than we either are aware of or altogether prepared to handle. The routine engineering task is not going to be done by the graduate of the engineering school. In many cases it can be handled more effectively by the graduate of a technical institute. If you want a good technician to do a surveying job, a job that used to be done by engineers, you are now better off to hire a graduate of a technical institute.

We are going to see much further development in the effective use of analysis, perhaps I should use "applied mathematics," and of engineering science, or "applied" science or "applied" physics, what you will, in our engineering work.

Preparation for Design

Another significant change that's going to take place in our outlook, certainly as far as education, is the task of preparing people to do design work. I speak

of design work in the large sense that some people would prefer to describe as "engineering synthesis." This is going to be changed a great deal in that it is going to be placed in a position where we are more concerned with the methodology, with logic of design, and the approach to doing designing, and also we're going to be in the position where we want to use in our design job all of the power of applied mathematics and applied science we have available. If we do not do that in engineering, we are not going to be doing a significant job.

I want to talk in more detail about this matter of engineering science in the engineering curriculum. I want to talk about it in relation to the problem of applied mathematics, or mathematics in any sense in the engineering curriculum, because I think there is a great deal of relevance and in a sense sort of a case study. We have in this area of engineering science, which has been growing in significance and consequence in our engineering curricula during the last ten years, something which may parallel what is happening with regard to mathematics.

The engineering science area is the area of physical science, which is most frequently applied or is applicable to the problems of designing, analyzing, and testing engineering systems. An engineer formerly was trained in the fundamentals of physics, and these fundamentals, along with the well-established practices or procedures of engineering analysis which he had, were sufficient. But as we know within the last twenty years, this is no longer sufficient. The engineer must have at hand a great many more tools and a broader understanding of the fundamentals of science which have been established as applicable, or potentially applicable, to engineering problems than he formerly had. We realize this fully and it is now well represented in our engineering curriculum. All of you are familiar, of course, with the procedures by which this was formalized in a report on the evaluation for engineering education and are familiar with the subsequent studies and steps which have been involved in getting this into the engineering curriculum. There is scarcely an engineering school in the country which does not accept the importance of this area in their program.

However, a significant aspect of engineering science is that it could be described quite easily, in many cases, as applied physics. For example, what is thermodynamics but a branch of physics? What is electricity and magnetism but a branch of physics? What is applied mechanics but a branch of physics? You could take all of these areas and say, "You're not talking engineering, you're talking physics." And yet we find, without exception, that this material is taught by engineers as part of the engineering curriculum and is accepted by anybody who is concerned as a legitimate activity for engineers as part of the engineering curriculum. To be sure, they are doing more than just teaching the pure scientific aspects, although in fact the objective of the engineering curriculum is to give the student a basic and comprehensive familiarity with the physical principles involved as applied to engineering problems. In other words, there is a concern with the broad principles and modes of analysis because it is to be applied in engineering situations. This is different from the physicist. The physicist gets his fundamental knowledge because he knows he's going to use this knowledge in order to further his understanding of physical phenomena. He's not going to apply it to an engineering situation, but the engineer is. This is a significant difference, and yet the completeness in the engineering science material is distinct from the former traditional analysis of engineering design systems; the completeness now is the completeness as far as the underlying physical theory is concerned rather than a completeness with regard to engineering practice.

In the field of thermodynamics, for example, as it is being taught now and as it is developing in our engineering curricula, we are concerned that the student have a good understanding of the basic principles in a broad manner, but we are relatively unconcerned as to whether he

acquires a familiarity with all practical devices with which an engineer has to deal in production or his application to practice. We've made this change for many reasons. Among many other practical reasons, engineering has proliferated to the extent that you know perfectly well you can't possibly give the engineer a familiarity with all current devices and systems, so that what you do is give him familiarity with the underlying principles and show him how they are applied to representative situations. With this, he can carry on when he gets out into industry or wherever he is going to work. He'll have a knowledge of that basic information which is to be used, and a knowledge of how it is used in an engineering situation.

Thus, there is a whole area, essentially physical science, which is taught as engineering. Then you come back to the question, if this is true (and this is a question people have asked rather searchingly), why bother with any instruction in physics at all? Let's eliminate the physics instruction. An engineer can do a better job of teaching dynamics than a physicist; he can do a better job of teaching electricity and magnetism than a physicist; he can do a better job of teaching thermodynamics than a physicist. So, why bother with any physics instruction at all? This is a question which I think the physicist perhaps can answer better than the engineer. However, there are several reasons why we will always have to have some physics in our engineering curriculum. Probably the physicists can give a more objective introduction to physics than can an engineer. Perhaps this is a really good thing for an engineer to have, because even in engineering sciences and even with the current emphasis in breadth and fundamentals the engineer is talking about the sort of things he anticipates may be relevant—even though they may be things which are not developed. The physicist is talking about completely objective broad concepts from the point of view of the nature of the physical world, so he can be more objective than the engineer can be. He can give better emphasis to the philosophy of physics and the general area of physical sciences. Futhermore, the physicist in various levels, not necessarily in introductory levels, can give the engineer some vision as to some of the areas which are in the process of development, which are not yet even contemplated as far as application to engineering, in a way that the engineer cannot give. The physicist can give the engineer some insight into the developing areas in physics itself.

The Meaning for Mathematics

What does all this mean with regard to instruction in mathematics? I think now you can see why I dwelt on this parallel in engineering science. There is very likely, and in fact there is occurring, a similar development. This development which we have been alluding to is the mathematical instruction which takes place in the engineering curriculum itself. Thirty years ago it was practically nonexistent. The engineering student frequently had only one year of introductory mathematics. Sometimes after learning his calculus, and completing his engineering courses, he never used his mathematics again. This is now completely changed, perhaps not as much in some schools as would be desirable, but certainly the basic viewpoint is that this is to be changed. Any engineering faculty that is not in the position of making effective use of mathematics and not yet doing a certain amount of mathematical teaching in its own courses is probably sensitive to this point and is making efforts to change.

There are several aspects to this matter of how mathematics gets into the engineering courses. The first is that more and more, on the basis of the emphasis on analysis which I referred to earlier, the engineering student must have a very effective skill in the use of mathematics as an analytical tool. He's got to use it over and over again; he's got to use it easily. It used to be that the engineer had to be extremely skillful in doing things with his hands in the shop. He had to be able to make everything; he had to be able to set up his test equipment;

he had to be skilled manually from a technical or mechanical standpoint. We can say now that the engineer needs a comparable type of skill and as effective a skill in mathematical techniques. Our problem, then, in our engineering courses is to insure that he acquires this. It doesn't always happen in his mathematics courses. We find in our engineering courses certain areas of mathematics which are systematically developed essentially as mathematical skills for use just as in our engineering science courses we find topics in physics developed in the engineering context. Vector analysis, for example, is taught frequently now as part of engineering courses, and sometimes taught very well. In my own institution in freshman engineering courses, we teach our students vector analysis practically the first week, before they are quite aware as to what the mathematicians are doing to them. The area of complex functions has been mentioned. Certainly this is something which is taught in engineering courses. Electrical engineers do an excellent job of teaching Laplace transforms, in many cases with a substantial amount of mathematical rigor. We could go on to other areas on a more advanced level in the applications of partial differential equations, linear algebra, probability and various areas which are developed systematically as part of engineering courses. This is going to continue in the future and to be developed more than it has been in the past.

Just where this is going to go and how it should be balanced is hard to pin down, but I think it's an inevitable trend. One of the questions to which we don't know the answer is, "What is the job of the mathematician with reference to the training of the engineer?" It seems to me there are two or three things which can be pointed out very clearly.

Mathematician's Responsibility

Certainly the mathematician must accept the responsibility of getting the engineering student started in his acquisition of facility in handling mathematics as a tool. Furthermore, quite closely associated with this is the responsibility of the mathematician to persuade the student who is going into engineering that mathematics is something useful, that it is something which he should be willing and enthusiastic to use as a tool, and that it is something that is going to be relevant to his own area of investigation. I stress this because in the enthusiasm to give the student a good appreciation of principles and concepts so that he will have a broad basis of mathematical foundations, sometimes the importance of motivation with regard to the use of mathematics by the engineer is overlooked by a mathematician. Students may then come into engineering courses with the feeling of antagonism towards mathematics—which is certainly unfortunate and undesirable.

A general question involves the role of those mathematical topics which are parallel to certain developments in engineering courses. We had mentioned a whole series of such courses this morning, and the question was raised as to whether these should be taught by engineers or mathematicians. I think this is probably going to work out at different institutions in different ways, because it depends upon the faculty, and it depends upon their interest. But certainly the areas of advanced algebraic fields of all types are ones which the engineer is going to have to learn more and more about. The general field of vectors and tensors and the more general vector spaces are examples. The whole field of statistics and probability is an area which is very much involved in engineering analysis but which has its broader aspects as well.

Now, let me go on to one other point which, again, has a very close parallel to the history of this situation in engineering science. I have been stressing the fact that the mathematical aspects and portions of the engineering courses in the curricula are increasing. One of the biggest problems in connection with that is the mathematical competence of our engineering faculty. We had exactly the same problem with regard to engineering science. There are various ways by which this problem is solved, many

of them obvious, but it remains a problem. One of the complaints of the mathematics faculty is that many times the engineers have said, "Well, our students need to know the Laplace transform." So the mathematics department finally puts this in, and then after a couple of years finds that the engineering faculties never make use of this information. The reason for this is that the students know the material, but the faculty doesn't. The students could use it, and use it to advantage, but the faculty hasn't the vaguest idea what a Laplace transform is all about. If you took a poll right now of the engineering faculties over the country on that very subject, I think you would be a little bit dismayed as to what the engineering faculties didn't know. This is a problem which must be solved ultimately for the engineers to do their own job. The engineers must inevitably use more mathematics.

You also do not solve this problem by waiting for people to retire. At least you don't solve it quite as quickly as you want to. Because, you see, not only does it take a while for people to retire but the people who are retiring have been training the engineers that you are going to hire as their replacements. So, these engineers aren't going to know the application of mathematics as effectively as they ought to. Of course, you can convert mathematicians to engineers. This has some advantages, but it has some disadvantages, too. You lower your supply of mathematicians, among other things. So, somehow or other, this is something that must be faced. There must be a group of people, both in mathematics and engineering, who have a constant and active concern for the continual injection of mathematics into our engineering teaching and into our engineering analysis. This is the thing which needs to be fostered at every possible turn because of the increased efficiency in our engineering work which results from it. As I say, this has to be done by people on both sides.

The engineering student himself, it seems to me, must acquire from his mathematical instruction, be it by mathematicians or engineers, three principal things.

In the first place, as an engineer, he must acquire a very high degree of motivation towards the use of mathematics, mathematics of the most sophisticated kind. If we do not attempt to motivate the students towards this endeavor, we will be doing both mathematics and engineering a disservice.

The engineering student must be able to use his mathematics as a tool. Now I do not say this in any depreciating form, but just simply as a recognition of its importance. You can talk about mathematical ideas; you may be motivated; but unless you can use it in day-to-day problems and analyses which the engineer uses at all levels, and really use it effectively, you've not accomplished anything.

Last, the student must have a very deep appreciation that mathematics can contribute very substantially to the engineering job as an engineering job. The student is getting an appreciation today that all aspects of physical science will contribute to his solving of whatever engineering job he will encounter. However we can do that, we'll be doing something very useful.

U. OF MIAMI STARTS ADVANCED PROGRAM

The University of Miami initiated advanced and graduate programs in engineering with the start of fall semester classes Sept. 18, according to UM President Jay F. W. Pearson.

Courses will be offered leading to the Master of Science degree in civil engineering and professional degrees in both electrical and mechanical engineering.

Engineering Students Must Learn Both Computing and Mathematics

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1. *Computer Use Today*

I shall open my remarks by describing the present state of automatic digital computers (to be called "computers" for brevity). These are developing so rapidly that even computer scientists cannot keep up with them. It must be bewildering to most mathematicians and engineers.

Modern automatic digital computers can not only calculate and make decisions automatically, but they can also do these things more than 100,000 times faster than was possible twenty years ago. This revolutionary increase in speed permits scientific computations of the sort done years ago to be done much faster, and yet this acceleration is but a small aspect of the Computer Revolution. Much more significant is the vast broadening of the *kinds* of things being done with computers. These include the automation of such varied activities as forecasting the weather, controlling air traffic, keeping insurance and bank records, controlling factory production, playing chess, proving theorems, carrying out mathematical analysis, preparing concordances, composing music, and designing computers. Much of modern engineering, particularly in the fields of atomic energy and space technology, simply could not go on without the detailed simulation of large physical systems on an automatic computer. Still in the future, but under serious study, are the uses of computers to translate foreign books, to retrieve vital information from libraries, to simulate a national economy, and to learn to recognize written characters.

In spite of the diversity of the applications, the methods of attacking the different problems with computers show a great unity, and the name of Computer Sciences is being attached to the discipline as it emerges. It must be understood, however, that this is a very young field whose structure is still nebulous. The student will find a great many more problems than answers.

Machines are directed by a succession of detailed instructions, each of which is obeyed in a few microseconds. Since many problems require for their solution the execution of millions of these instructions, it is impossible for human beings to prepare a sufficient number of them, and machines must prepare their own instructions. This has led to the design of a hierarchy of languages and a corresponding series of machines programs, each of which prepares instructions for the next lower level in the hierarchy, based on directions received from the next higher level. Moreover, these machine programs must themselves be written by machine. The study of these activities is called the theory of computer programming, and it is perhaps the most important of the computer sciences, since it pertains to all possible applications of computers.

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Another task common to the solution of any problem with a computer is the preparation of a complete description of the problem and an algorithm to solve it, a description without a single loose end untied. The language for this description is influenced by those developed in the theory of programming. Often a problem is better understood and half solved as a direct result of preparing this complete description. Thus the computer sciences are partly independent of actual automatic computers, and have a significant feedback to the areas of application.

Other computer sciences include numerical analysis, the study of data processing, and the design of computer systems. These have been studied longer than the theory of programming, and are better understood and more available in courses.

2. *Computing at Stanford*

Let me describe the situation at Stanford, which is reasonably typical of dozens of universities in this country. Although we have a slower computer than many top universities, almost no other university has as good a language for rapidly and easily writing programs for the computer.

We have a Burroughs 220 computer with 8000 words of memory that are accessible in microseconds. We have five magnetic-tape transports, each of which can hold about a half-million words with access times down to half a millisecond. The arithmetic unit multiplies in an average of 2 milliseconds (decidedly the weakest part of our system). We have punched-card input and output and on-line printed output. There are other features of less relevance here.

Although there is a machine language and a good symbolic assembly language, about 95 per cent of the programs are written in the Burroughs form of ALGOL. At the beginning of 1960 an international committee[1] defined ALGOL as a standard language for the communication of mathematical and logical algorithms. This is a considerably more sophisticated language than FORTRAN, in this country perhaps the best known of the algebraic languages. In ALGOL one can describe sequences of instructions like those for evaluating a polynomial. One can group such sequences into packages called *procedures*, which then can be temporarily added to the structure of the language and used to build other structures. This is the real power of ALGOL. For example, one can write a procedure for taking the inner product of two vectors. One may then use this as an elementary operation in building up a matrix multiplication procedure. One may then use matrix multiplication as a unit in a matrix function evaluation procedure. And so on. All features of the language permit unlimited finite recursive depth of nesting. Boolean variables and logical operands are also allowed.

Now, the Burroughs Corporation has written a program[2] by which the Burroughs 220 can translate programs written in the Burroughs form of ALGOL into Burroughs 220 machine language. Such a program is called a *compiler*, because it compiles a program out of algebraic input. It happens that, although the 220 is a slow machine, the Burroughs compiler writes code considerably faster than most comparable systems. The result is that users rarely keep their compiled programs, but prefer to recompile them each time they use the computer.

Of course, the great value of ALGOL and other languages is that it returns to the engineer or other user the direct control of the solution to his problem. When machine language was used, preparation of a program was so slow and tedious that one normally hired professional programmers to write a code. Moreover, one rarely knew just what the program did, because machine code is so tedious to read. Today, with ALGOL, an engineer can learn to write his own programs in ten hours of study. Programs can be written perhaps fifty times faster than formerly. Moreover, programs can now be borrowed from all over the world because of the standardization of the ALGOL language. If one doesn't have time to learn to write ALGOL, one can

still hire a professional coder (they may even be getting easier to hire!) but now one can personally read and check the program. It is in this way that the engineer is regaining control of his own problems. He may still have to trust the computing center for the accuracy of the subroutines and operating system, and for packages like matrix inversion routines.

At Stanford anyone can give the computing center his ALGOL deck for a short problem at 9:00 a.m. and be sure of having his answer by 11:00 a.m. If he stands around, he may even get two or three runs in that time. He can get various types of traces and print-outs and monitors and error messages to assist his debugging of the program. This is a workable system. One can conceive a problem on one day, write an ALGOL program in the evening, punch the cards at 8:00 a.m., and have his answers by 10:00 a.m. I do this regularly in connection with class work or research—for short problems. Similar two-hour service is possible in the afternoon.

Roughly the same things are being done at Michigan with the MAD compiler, by M.I.T. with the FORTRAN compiler, and at other universities in other languages. (I cannot vouch for their operating schedules.) The computer has been put into easy communication with anyone who wants to use it.

A lot of research is going on in the theory of programming, much of which is concerned with how to make this communication between problem-solver and machine as easy as possible. In particular, we need to know how to make quick and cheap transitions from machine to machine. Since a university must expect to change machines every three years, more or less, it is vital to know how to make the language for one machine serve for the next machine. The faculty simply cannot be expected to make the language transition every three years. The solution seems to be along the usual lines of computer development—the design of still other programs to write the translator programs. Thus the hierarchical structure of programs continues to grow higher.

3. *Need for freshman computing course*

I assume that the purpose of today's engineering education is to train a student to solve the engineering problems he will meet in his working lifetime—that is, until past the year 2000. For this role the student needs some relatively concrete tools, such as a knowledge of circuit theory or of contemporary literature on materials, and this is furnished entirely by the engineering departments. In addition, he needs some abstract analytical tools, and these are usually furnished by such outside departments as Physics, English, Statistics, and Mathematics. With the vastly accelerated development of the technology, engineers realize that the abstract tools are the more useful, because of their slower rate of obsolescence. As the most abstract of the tool subjects, mathematics is receiving much attention in current engineering curriculum studies. (I think in today's discussion that we may ignore mathematics as an art form.)

I should like to propose that an automatic digital computer is an engineering tool which is very abstract in its application and very powerful. For many problems facing the engineer, its effective power and its effective abstraction may be as great or greater than those of mathematical analysis. While the potentialities of this great power are only beginning to be realized, they will certainly be commonplace within the first decade of the new engineer's practice. For this reason it is essential that the engineering student become thoroughly conversant with computers during his university period.

Because of the abstraction and versatility of computers, they can be made to simulate various mathematical processes, and are widely so used. To you engineers and mathematicians the use of a computer as a tool in applied mathematics is probably the most familiar of its uses, and it is certainly the use which has so far received the most research effort. The use of computers in this way does a great deal to illuminate mathematics, especially for the student, and it

certainly helps to solve problems. But the analogous statement can be said for the use of computers in theoretical physics, in composing music, in playing chess, in guiding air traffic, in controlling industrial production, in forecasting the weather, and so on. In the long run, the importance of computers in the education of an engineer is the realization that such a variety of things are being done more or less well with computers today, and that computers will do far more for his own problems in future years.

Now mathematics is also used in very many different areas of science. It is, therefore, generally agreed that mathematics should mostly be taught in one department by specialists, rather than separately all over the campus. This is especially true of the introductory courses. In the same way, the introductory courses on computing should be taught in a unified fashion by computer experts. (In the first approximation, users of computers in different areas are very close to each other in point of view, vocabulary, and so on. There is a unified body of knowledge in computer use, and it is growing rapidly.) I consider it imperative that all students of engineering (as well as natural science, social science, and mathematics) become intimately acquainted with computers, and that they do so during the first year of their university work. (I am happy to learn from CUPM literature that the first year of engineering education is rather "soft," because I have plenty of material to put into it!) These courses must be taught by specialists, and must be laboratory courses. It doesn't seem to matter whether you call this mathematics education or not, as far as the student is concerned, so long as they are taught by computer scientists of broad vision. The thing to avoid is to have such a course taught by someone who thinks it is just mathematics, or just engineering, or just business administration, or what have you. For then the student will miss the whole point of the power and generality of computers. (It is also my opinion that such courses will be developed more rapidly if they are staffed by individuals not judged primarily by the standards of any existing academic department.)

4. *Content of Introductory Course on Computers for Freshman Engineers*

I think of this tentatively as being a four semester-hour course, offered early in the student's university curriculum, with no prerequisite except high school mathematics. On the other hand, it probably should not be offered until at least one other course is ready to make use of computers. Only experience will say whether more than four semester hours are needed. I consider that the course should cover two areas, and that time and energy should be divided approximately equally between them:

(1) Stirring the student's imagination as to the really significant possibilities of computers and their great versatility and power. The student must get an idea of what is meant by saying that a computer is not just a super slide-rule.

(2) Teaching the student to use the university computing laboratory—its key punches, and other card equipment, and a simple automatic programming system on its automatic digital computer. This should be done as a lecture-plus-laboratory course, with each student having plenty of time on the computer.

As a syllabus for part (1), a principal source is Hamming.[3] This syllabus is given below. I would myself try to cover fewer areas of application, and do each more slowly, since it is to be expected that the engineering students may actually use computers to do many of these things later. (Hamming was thinking more of a computer-appreciation course.) I would moreover try to introduce some of the applications as examples for the laboratory part of part (2) of the course. Since these are engineering students, I would also devote more attention to showing the students how computers can be built up step by step from abstract binary decision elements (*and*, *or*, and *not* elements) to adders and arithmetic units, etc.

Besides (1) and (2), the course should achieve two collateral benefits: First, it should develop a few computing en-

thusiasts who will later learn the field deeply and contribute to the university computing effort during their stay at the university. These should be discovered in the freshman year. Second, the course should help the students to understand some of the concepts being presented in the concurrent mathematics course.

One of the points of views that the student should learn is that, because on modern computers input and output are relatively much slower than computation, it is vastly more efficient for a computer to regenerate information than to retrieve it from its own library. As an elementary example, one does not store tables of sin x in a computer; rather one computes sin x (approximately) whenever it is needed. In a similar way, it is to be expected that computers will generate integration formulas as needed, instead of storing a large collection of formulas. This fact is probably relevant to the proposals of storing university engineering libraries in computers for ready access. It may turn out to be more efficient to store only key principles, and to re-create the consequences as needed.

Here is roughly what should be covered in the practical part of the course:

Machine representation of numbers (fixed point, floating point), of alphabetic information, and other kinds of information.

The machine language of the computer available to the student—briefly.

The fundamental ideas of the stored and dynamically modified program. This concept of the feedback loop is one of the leading ideas in modern technology.

A symbolic assembly language of the computer—briefly.

An algebraic language compiled by the computer, in detail. This is the language the student is expected to use henceforth. We find at Stanford that we can teach our version of the ALGOL language in 10 to 15 hours.

A little idea of how the compiler actually operates on the algebraic language to produce machine language code.

Considerable student laboratory practice in using the algebraic language to solve a variety of problems requiring only high school background. For example:

- Adding 5 numbers.
- Adding 10,000 numbers.
- Sorting English words into alphabetical order.
- Evaluating a polynomial of degree 10; ditto, of degree n.
- Solving the general linear equation $ax + b = 0$, where a and b are arbitrary numbers.
- Generating the square root of x by an iterative process.
- Playing tic-tac-toe.
- Preparing a concordance to a brief passage.
- Finding the area of a plane figure by a Monte Carlo method.
- Writing a code to recognize the digits 0, 1, 2, . . . , 9 from an optical scan.
- Simulating a queue waiting for service and experimentally determining the optimal number of servers.
- Preparing a code to multiply and divide polynomials.

Defining these problems in detail and finding other ones which are suitable are the most vital part of preparing this course.

5. *Should Students Push Buttons?*

In connection with the laboratory work on computers, one question recurs very often. Does a student need to learn to push buttons himself on a computer, or is it sufficient to program in some abstract system and get his output back later, without personally pushing the buttons?

The answer on economic and educational grounds is that the student must forego the button-pushing, and deal with the computer exactly as he must in later practice, through the intermediary of a coding and operating system. Incidentally, I have changed my mind on this as the computer revolution has progressed.

The issue is not one of pushing buttons. The issue is how best shall man-machine teams operate—not one man-machine team, but hundreds and thousands of man-machine teams? Digital

computing time is far cheaper when money is consolidated into the one most expensive computer that a university can afford, together with plenty of "software" in the form of compilers and operating systems, and plenty of human consultants. Moreover, only the large systems even have the capability of solving the larger computing problems. Computers are vastly expensive to operate, and there is a great shortage of talent. No university can afford to splinter its resources in many separate computing centers. The effective benefits of separate computing centers can be achieved in another way—by supplying adequate communication lines from different points on the campus to the central computing center.

The whole matter of personal struggle or cooperation with a machine can be achieved through programming systems. At Stanford 95 per cent of the programs are written in our ALGOL language, and most are checked and run in that language. The need to push a button is basically the need to ask a machine a question about a program, and questions can be asked and answered in the ALGOL language, as long as turn-around time is limited to a few hours. As long as the computing center has the money, the personnel, and the determination to provide good service, it can do it far more cheaply than any combination of separate facilities. And the student will learn far more about computing.

Finally, if an occasional student really wants to go farther—to learn the operation and design and maintenance of a computer—he can learn this himself by hanging around the central laboratory and later getting a job there. This connection is not appropriate for the majority of students who pass through engineering school.

6. *Later Courses on Computing*

After the first year's introduction to computers, I think applications had better be left to the various departments. These include much of a university, for in today's technological world the computer is a major tool. Most, if not all courses, in all scientific and engineering departments, should therefore be taught by faculty who themselves understand the abstraction and power of computers. They should, moreover, make clear to the students where computers are relevant to their course.

As far as engineering students are concerned, there are now appearing studies about where computers can help engineering courses.[4] This is not my subject, nor is the use of computers in physics, chemistry, statistics, psychology, etc. I am to suggest what relevance computers have for the mathematical education of engineers.

Before going to that, let me add that there should also be advanced courses specializing in the exploitation of computers taught by experts, and available to any who wish to specialize. However, for the most part these should be senior or graduate courses, since the student must learn much mathematics, logic, statistics, and so on, before he is mature enough to comprehend the deeper problems of the computer sciences.

7. *Computers and Teaching Basic Concepts of Analysis*

And now, what effect should the computer age have on the teaching of mathematics to engineers? Engineering students tend to be rather concrete-minded. A working model means more to them than an abstract concept. Although computers are inherently abstract, they can be programmed to do rather concrete things. The very detail of a computer description in microsyllables may help students to realize the meaning of difficult concepts like "function." Consider the absolute-value function $f: t \to |t|$. What is meant by the function f ? Well, how might one code the calculation of $|t|$?

Start: Clear accumulator and add t.
2: If accumulator is positive, go to 5 (otherwise, go on).
3: Store accumulator in location u.
4: Clear accumulator and subtract u.
5: (Accumulator now contains $|t|$.)

The absolute-value function f may be thought of as being this block of code, with the symbol t left out. The code is a working model of the function f. A flow chart would do just as well. It is difficult to confuse the block of code with the number that is left in the accumulator; the latter is the value $f(t)$.

Existing computers can furnish working models of any concepts involving finite constructions. Naturally they cannot model *derivative, integral,* or *real number.* However, it is my opinion that students often fall down in learning these concepts of analysis because they haven't enough experience with finitely constructable numbers. One has a much better feeling for the limit of a sequence of numbers, for example, if he has seen initial segments of many sequences of terminating decimal numbers that are (apparently) converging.

Once a student is familiar with actual computers and flow charts, it is possible to extend the concept of a flow chart to an ideal flow chart in which an iterative loop is allowed to be passed an infinite number of times. Thus one can define the square root function $g\colon t \to \sqrt{t}$, for example, by the Newton process (written more or less in ALGOL). Assume $0 \leq t < \infty$.

```
Start: y := 0.5;
     2: z := y;
     3: y := 0.5 × (x + t/y);
     4: if y ≠ z then go to 2;
                (otherwise, go to exit)
exit: f(t) := y;
```

These ideas have been exploited by A. J. Perlis and H. R. Van Zoeren at the Carnegie Institute of Technology, who are teaching such a course to freshmen. Perlis even introduces the logarithm function and proves its fundamental properties by means of a flow chart. Having tried to teach the logarithm as the integral of $1/x$, I am ready to try the flow chart!

In summary, computers offer models that are capable of extension to represent most of the concepts of analysis. They may therefore be used to help explain the concepts whose elaboration forms most of the content of early college mathematics.

Basically, I suppose the difficulties that students have with abstract computing courses are the same as those they have with mathematics. Namely, they are confused by the very generality of the concepts of variable, function, recursive definition and so on. Mathematics and computing courses should tend to reinforce each other, by introducing many of the same concepts in different settings.

8. *Theory Courses and Practice Courses*

Besides introducing concepts, mathematics courses are expected to teach engineers how actually to solve important classes of problems. Presumably the formulation of engineering problems in mathematical (abstract) form is the province of the engineering courses, but teaching techniques for their solution surely belongs to the mathematics department. This means the teaching of algorithms for transforming the statement of a mathematical problem into a representation of its solution.

It is here that computers enter the picture. At the present time automatic computers are the main tool with which algorithms are actually carried out. With the advent of algebraic languages and versatile monitor systems, it hardly ever pays to perform by hand or with a desk calculator any routine algorithm whatever. Furthermore, each year the meaning of "routine" grows. At the present time one routinely refers to a computer the following types of problems:

- evaluation and tabulations of function values, integrals, etc.;
- solution of linear and nonlinear algebraic equations;
- solution of ordinary and partial differential equations;
- solutions of functional equations; etc.

Consequently the engineering schools have every right to expect that the mathematics department will teach its students how to do these things on computers, and that these techniques will be taught in the regular prescribed sequence of mathematics courses.

At the present time, computers are used rather concretely for these problems. For example, the human with a differential equation selects the integration formula, and then asks the computer to carry out the integration with the selected formula. It is clear that in the future more and more of the selection of methods will be turned over to computers. There will be a slow but revolutionary progress in the uses of computers for the generation of algorithms based on appropriate specifications.

Moreover, computers have great power in dealing with algebraic symbols. It may be expected, as Hamming points out for example, that computers will go through a substantial number of standard transformations, to find out whether a given differential equation can be reduced to one whose solutions are known in closed form, or are tabulated.

The present tendency in mathematics courses is to split the theoretical study of a field from the practical solution of problems in it. Thus there are courses in differential equations in which theory is taught, perhaps augmented by some elementary transformations and maybe a chapter on numerical methods (often archaic). Then in another course numerical methods will be treated—either as a special course like Mathematics 137 at UCLA, or as a unit within a numerical analysis course for undergraduates.

I believe that this separation of theory and practice is wrong, and that both the theory and the practice suffer from it. Certainly time is lost in the practical courses because some theory has to be retaught. Hull[5] has pointed out that existence theorems in differential equations can be improved simply by introducing better numerical methods into the proofs. I therefore recommend merging the theory with the practice just as soon as teaching material can be written. And the first materials are appearing now. For example, Block and Ruoff[6] have written a differential equations book for engineers that starts with computer programming and later includes analog computers also. Throughout the book the reader is reminded that he may be expected to obtain either a computer solution or an analytical one. Similarly, linear algebra books are beginning to admit the existence of computers.

The alternative to this merging of theory and practice is that the mathematics department will lose even more contact with the reality of the application of mathematics to engineering.

Actually the gulf between theory and practice is probably less than you might think. The way of solving problems on a computer is often closer to the definition of a concept than to the constructs that have been built up in order to solve problems by pencil and paper. Consider a problem that was brought to me recently by two physics graduate students. They wanted to integrate over a rectangle in the xy-plane four well-behaved rational functions F of $\sin x$, $\cos x$, $\sin y$, and $\cos y$. These functions F had denominators of sixth degree. The students had been working for weeks to reduce the rational functions to partial-fraction representations in terms of $\tan (x/2)$ and $\tan (y/2)$. They knew they would get about 100 separate integrals that could be evaluated in closed form. I believe everything they wanted could be obtained by evaluating the functions over a network of perhaps 100 points in the rectangle, and then applying the trapezoidal rule in two dimensions. This could all be written in ALGOL in one short evening.

Why hadn't the students thought of doing this? I believe the answer is clear. They had learned the definition of a double integral as something remote and conceptual. Perhaps their instructors implied that one never actually used the definition in practice, but always went over to an iterated integral, and there had to transform the problem if possible, in the traditional fashion intended for analytical solution of simple functions. Numerical integration might be used if the integral could not be treated in any other way.

It is also notable that in solving ordinary and partial differential equation problems, the equations solved on a computer are usually more fundamental

equations than those solved by analytical methods; the latter often are the result of ingenious special transformations.

There are other places where pure mathematical theory and computer practice come close together. Each has as its object the construction of universal mechanisms to solve large classes of problems, rather than the creation of bright tricks for the more efficient solution of particular cases. Complete and rather formal descriptions of problems and algorithms and methods are needed for computing as well as for a theoretical structure.

For many problems it is not nearly so important to create an efficient algorithm as to create one quickly and to make it general enough to avoid having to recreate it next time.

9. *Total Mathematics Course Requirements*

I do not believe that the addition of contemporary practical methods to the various theory courses in mathematics can be done without an increase in the total mathematics load of engineering students. Some consolidation may be possible from the tendency of theory and practice to be closer together in the computer age, and a little obsolete theory might be eliminated. Perhaps some engineering courses will be shortened with the availability of the computer as a tool (this has been reported in the Chemical Engineering curriculum at Michigan). Some gain will come from better preparation in secondary school. But, in the end, as the technology grows more sophisticated, education must take longer.

Can this be doubted? The question is what things to add, and what to eliminate. The things to add must be general, powerful tools, of which the automatic digital computer is one. The things to omit must be the very special ones.

10. *Computing in Various Mathematics Courses*

One may ask which computing topics should enter which mathematical courses. Some ideas are presented by Forsythe[7] and Tukey[8] and in the CUPM literature. But I think the main thing is to give our mathematics instructors some interest in teaching engineering students and to give them a good foundation in what modern computers can do. At this point, they are likely to see for themselves where to bring the point of view into the courses.

A great financial reward is surely waiting for the writer of good textbooks in these areas. I expect this to encourage textbook writers to bring the material into courses.

It seems to me that perhaps students themselves may provide the incentive for instructors to learn about computing. Suppose every member of a freshman spring-semester course in calculus has had a good rousing computer course in the fall term. Will not the students ask why one should learn to do analysis by pencil and paper? Will they not question the value of a number of techniques now taught? What happens when they turn in graphing problems plotted on the computer? Will they not be better students for having a technique already available to them for solving many calculus problems to engineering accuracy? Or will this hinder their learning the calculus?

Take the matter of finding a relative minimum of a differentiable function. The important matter is that the minimum occurs at a zero of the derivative. This is a conceptual point of great analytic importance. When it comes to finding the minimum of an actual function, it may or may not provide a useful way to proceed, depending on the function and on the tools at hand. I think most mathematicians realize this, or I hope so. But with calculus books written as they are, I wonder how the student of mathematics is supposed to learn this. Usually he is faced with a large number of cute functions which are all differentiable in tidy form, from which he is left with the natural conclusion that differentiation or other pencil-and-paper graphing is *the* practical way to deal with minimum problems. Why should it not be stressed that it is the concept that really matters, and not the practice? It seems to me that perhaps the student would be helped if he already knew how to use a computer

to approximate the minimum of those functions to reasonable accuracy. It might make clear to him the role of differential calculus as a microscope finer than a computer can ever be, to be used exactly when such a powerful tool is needed, and not for other purposes.

I do not want to oversell the effect of computers on a calculus course. I feel that the calculus course may have less to profit from an awareness of computers than many of the technical courses an engineering student will take in his university career. The awareness should be there, of course, and this means each mathematics teacher must know something about computing. And I believe computing can illuminate many concepts. But modern calculus courses tend to get away from technique and problem solving, and emphasize concepts. And surely there is a limit to the role of computers at this point.

Much more can be expected from computers in connection with differential equations. While there are important concepts here too, we are now building on the calculus background, and are closer to trying to help solve engineering problems. At this point, computers enter more urgently, and there is very much to say.

Linear algebra is another course where many concepts are introduced. It differs from calculus, however, in that there are very many practical problems whose complete solution should be ordinarily carried out on a computer. And I would suggest that the definition of the concepts of rank, determinant, dimension, null space, inverse matrix, etc., can and should be made in terms of the output of an algorithm with an ideal computer that doesn't make round-off errors. Without necessarily saying so, the algorithms should be those which are relatively stable when round-off errors are introduced. Thus, in pivotal condensation for solving a linear algebraic system one should search for the largest pivotal elements in columns or rows, instead of merely avoiding zero pivots.

It is true that computing involves a choice of basis, and that abstract linear algebraists would like to be independent of bases. However, I'd rather introduce linear algebra with components, and only eliminate them later, preferably in later algebra courses.

Whenever mathematical algorithms are performed on a digital computer, the question of round-off error arises. This is a comparatively difficult subject to analyze well, although in the past year an adequate and useful treatment of round-off in floating point operations has been given by Wilkinson.[9] I believe that any general treatment should be left to the specialists in graduate numerical analysis courses. However, instructors of all technical subjects should show an awareness of the problems raised by catastrophic cancellation!

11. *Hamming's Computer Appreciation Course*

The following is an outline of a 36-hour computer appreciation course, taken by permission from Hamming. It was designed to cover a lot of ground for a broad class of liberal arts students.

Lecture 1. *History of Computing* — perspective.
Graphs on growth of computing as an art as well as volume of work done. Shows some perspective of the whole field.

2. *Hardware*
Typical machines, emphasis on imput and output, speed, reliability, and minimize detailed circuitry.
Peripheral equipment

3. *Simple Coding Ideas*
Flow diagram
Block diagram
The necessity of giving full details is the one idea of the lecture.
Perlis' simple equations as an example of clarity resulting.

4. *Sorting and Ordering*
How to sort, collate, etc.
Making concordances
Study of writing styles
Authorship: when written, etc.

Necessity of a statistical approach
The power of a statistical approach

5. *Statistics and Data Reduction*
What, how, and why
Idea of a statistical test is the main idea of lecture.
6. *Information Retrieval*
General problem
Avoiding it when possible
Methods proposed
Encoding of information
7. *Machine Translation* — Russian to English mainly
History, some samples, methods used, troubles, etc.
8. *Language of Coding* — coding is a language
Beginning of automatic coding
9. *Automatic Coding* — changing the language of communication to adapt it to human use
10. *Systems of Operation* (monitor system principles)
Necessity of a monitor system
What it does for the user
11. *Linguistics Generally*
12. *The Need and Role of Redundancy*
In machine
In language
13. *Pattern Recognition*
Importance
Wide range of examples
General ideas
Optical experiment
14. *Handwriting and Symbol Recognition*
Provides input to a machine —how recognition is done
15. *A.P.T.*—machine tool control
An example of a language of description
How tool works
Economic gain by avoiding inventory
Probable extensions of technique
Automatic factories
16. *Control in Strange Environments*—space travel
Telemetering
High temperature places
Low duty cycle and low maintenance
17. *Inventory Problems*
Airlines reservations
Airport control
Chicago traffic control
Defense against multiple attackers
18. *The Idea of "Random"* — main idea of lecture
Outguessing machines
Monte Carlo technique
Random number generation
19. *Games*—(idea of a strategy is the main point)
Checkers
Chess
Optimization techniques
20. *Machine-made Music*—Creative aspects of art
Composing
Simulating instruments
New ways of looking at and testing old ideas
21. *Simulation of Experiments*
Machine simulation by another machine
Acoustic research at B.T.L.
Sampling theorem (lightly)
Wide range of simulation and its advantages
22. *Behavioral Sciences*
Group interactions
Evaluation of strategies
Simulators
23. *Biological Sciences*
Nervous system models and simulation
24. *Medical Research*
Diagnosis
Data reduction and pattern of symptoms
25. *Boolean Algebra*—Concepts and ideas of logic-law?
Income tax
26. *Turing Machines*—Idea of
Original use to prove theorems
Self-reproducing machines
Learning routines

27. *Mathematics* — Mechanization of
Algebra
Differential and integral calculus
Theorem proving in geometry—how done
28. *Education*
Teaching machines
Educational implications
29. *Economic Aspects of Machines,* including
Unemployment
Shift in type of working population
30. *Business Implications*—more control
31. *Social Consequences*
32. *Political Consequences* — more control of population
33. *General Implications for Art and Science* — meaning of creativity
34. *General Implications for Engineering*—
New ways of looking at engineering
New ways of doing engineering
35-6. *Examination periods*

FOOTNOTES

[1] J. W. Backus *et al.*, "Report on the Algorithmic Language 60," *Numerische Mathematik,* Vol. 2 (1960), pp. 106-136; and ALGOL *Communications of the Association for Computing Machinery,* May 1960, pp. 299-314.

[2] Burroughs Corporation, "*A Reference Manual, Burroughs Algebraic Compiler, 1961,*" approx. 75 pages. (Burroughs Corp., Detroit 22, Mich.)

[3] Richard W. Hamming, "Computer Appreciation Courses," paper presented at conference on use of computers in engineering education, University of Michigan, Ann Arbor, September 12-13, 1960.

[4] Donald L. Katz *et al., Integration of Electronic Computers into the Undergraduate Engineering Educational Program,* First Annual Report of Ford Foundation Project, College of Engineering, Ann Arbor, Michigan, August 26, 1960, approx. 600 pages. F. M. Tiller and E. L. Michaels, "Adjustments in the Mathematics Curriculum," outline of talk presented to Ford Foundation project in Ann Arbor, fall 1960. Dittoed, 3 pp., College of Engineering, Univ. of Houston, Houston 4, Texas.

[5] T. E. Hull, "A Proposal of Marriage," *American Math. Monthly,* Vol. 68 (1961), pp. 426-434.

[6] Henry D. Block and Arthur L. Ruoff, *Differential Equations in Engineering Analysis,* Preliminary Edition (Charles E. Merrill, Columbus, 1960), approx. 500 pages.

[7] George E. Forsythe, "The Role of Numerical Analysis in an Undergraduate Program," *American Math. Monthly,* Vol. 66 (1959), pp. 651-662.

[8] John W. Tukey, "The Teaching of Concrete Mathematics," *American Math. Monthly,* Vol. 65 (1958), pp. 1-9.

[9] J. H. Wilkinson, "Error Analysis of Floating-Point Computation," *Numerische Mathematik,* Vol. 2 (1960), pp. 319-340.

FORD GRANT TO CORNELL

A grant of $4,350,000 has been made by the Ford Foundation to Cornell University to further strengthen graduate study and research in the College of Engineering.

The grant will contribute toward the endowment of 11 professorships. It will also help provide substantial graduate fellowships and loan assistance, additional facilities for study and research, and will make other funds available for special purposes in the College of Engineering.

The grant will cover a period of 10 to 15 years. While the funds, and additional support which the University will seek on a matching basis from its alumni and other friends, will be confined to the College of Engineering, they will have their effect across the entire Cornell campus, Deane W. Malott, president of the University, declared in acknowledging the grant.

"Looking forward toward its Centennial Year, 1965, Cornell is placing first emphasis in its planning on the scholar-teacher as the foundation of excellence. The University welcomes this encouragement from the Ford Foundation and is seeking immediately gifts of $3,300,000 to provide a permanent endowment for the new professorships which will strengthen the graduate program at Cornell."

The Future of Engineering Mathematics
A Customer's Viewpoint

H. W. BODE

Bell Telephone Laboratories
Whippany, New Jersey

The curriculum recommended by the CUPM panel suggests that the major topic should be calculus; that there should be at least some brushing contact with computing; that a course in linear algebra would be particularly useful; that there should be some probability and statistics; that there should be some classical advanced calculus; and, if possible, that there should be at least one rigorous mathematics course, which might be an introduction to the real variable. On the other hand, the panel suggests that the traditional subject of ordinary differential equations may be somewhat de-emphasized. This curriculum sounds good enough to me, provided there is room for all of it, and I will return to it from time to time as part of my general discussion.

I speak simply as a representative of industry. Of course, the word "customer's" in my title is supposed to signify this. However, there are other key words in the title, which are important because they suggest problem areas. One of these is the word "future." It refers to the obvious fact that we are educating new engineers who will still be practicing their professions several decades from now. Clearly, to do this with effect, one should know what engineers and engineering some decades from now will be like, but such a prediction is not easy to make. Obviously, modern engineering is going somewhere with great rapidity —but where?

Another important word is the little word "a,"—because "a" is singular. I am, in other words, only one of many possible customers. My field of reference is electronics, not engineering in general, and my experience within electronics has been exclusively with research and development activities.

I introduce the point partly as a bit of escapism, but also partly because it underlines a second difficult problem, which confronts us as soon as we come to grips with the curriculum problem. This is the fact that engineering is really a broad field and there is no obvious a priori reason to believe that a single mathematics curriculum may be suited for all engineering students. I suspect that most of the people who have been planning mathematics curricula for engineers have been thinking in fact primarily of electronics R. & D., simply because this is such a conspicuous—one might even say noisy—field today. However, there are other fields of engineering and other kinds of engineers who have their claims also. We all recoil from the conception of a highly fragmented engineering. In most engineering schools, in fact, I believe that it is now stylish to have all the early work in an engineering curriculum common, so that it doesn't much matter whether a man is an electrical engineer, a mechanical engineer, or what not. However, it is not quite so clear how far one should try to carry such a program. Obviously, one cannot

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dig deeply into these questions without raising again the question of what the engineers and engineering of the future will be like.

Near the end of this talk I hope to say a little on this subject with particular reference to the relation between mathematics and the unifying themes of engineering. For the most part, however, I will try to illuminate the questions I have raised in the last few minutes indirectly by citing relevant Bell Laboratories experience. This will mean in particular a look at the kinds of engineers we try to recruit, the sorts of undergraduate training we look for in them, and the additional training we try to provide after they come with us.

Varieties of Engineers

Let me turn first to the varieties of engineers. Since the Bell Laboratories is essentially an electrical company, our staple recruit is an electrical engineer. However, we do also employ quite a few mechanical engineers, perhaps a third or a fourth as many as electrical engineers —and we would like to have even more in proportion.

The two kinds of engineers do differ significantly, of course, in background, interests, and aptitudes. For example, our electrical engineers usually have better mathematical preparation than do the mechanicals. However, in the long run I suspect that mechanical and electrical engineering will be a good deal alike. At the moment, electrical engineering is certainly riding a high tide. It's a very popular subject and one finds that electrical engineering departments are growing everywhere, sometimes at the cost of other branches. However, one must remember that years ago, electrical engineering budded off from mechanical engineeering, which was there earlier. People then didn't talk about inductance; they talked about electrical inertia. They didn't talk about capacity; they talked about electrical springs; resistances were electrical viscosities, and so on.

The mechanics antecedents of electrical engineering are still with us, and much of the fundamental theory is still the same. In fact, the snake is biting its own tail, so to speak. Mechanical engineers are beginning to take over from electrical engineering some tools that electrical engineers, particularly communications engineers, have developed. The analysis of the shock excitation of beams and similar structures by the methods used in electrical engineering for transients is a good example. So also is the adaptation to mechanical control systems of the methods developed originally for electrical feedback systems. While the two fields may be kept apart as a matter of convenience (and we do in fact keep them apart in the Bell Laboratories' so-called C.D.T. Program, which I will come to later), one feels that the basic mathematical foundations, and even to a large extent the basic physical foundations, in the two areas can logically be the same.

We also recruit a scattering of men whose basic training is in other engineering fields—aeronautical engineering, civil engineering, industrial engineering, engineering physics, and so on, but my experience does not allow me to say anything very definite about these fields. We recruit such men because of their personal promise rather than their specific training, so that for our purposes they could as well as not have been given the same mathematics as an electrical engineer would have.

Chemical engineering may deserve special attention simply because it is a very large field and one whose subject matter is so different from electrical engineering. (The importance of solid state electronics, and of elaborate chemical processing in the manufacture of solid state devices, may bring the two fields closer together in the future, but the principal impact of this is yet to come.) I note that the panel believes, nevertheless, that the two fields might require very similar mathematics curricula. To quote: "It seems to me that linear algebra no doubt must be as important to chemical engineers as it is to electrical engineers." Certainly chemical engineers need probability and statistics as much as electrical engineers, though perhaps for somewhat different reasons, and they probably have similar

interests in computing. But beyond that I can't very well go. It might be interesting to review these questions by a team representing electronics and chemical engineering specifically, to see how much the two areas feel that they really do have in common.

Differences in Curricula

Another problem which I raised earlier has to do with the possible difference in curricula for engineers going into R. & D. work, such as we might recruit for the Laboratories, and those going into other engineering occupations. Within the Bell System, these other occupations are represented by the engineers who go into the operating companies and into the manufacturing organization. These men are selected to less stringent requirements academically than the ones who go into Laboratories' work, and with perhaps greater attention to breadth. This divergence has not gone so far that there isn't a single community of interest and understanding of our technology, but it might go farther in the future. It is not easy to assure oneself that one recipe really solves both problems—particularly if R. & D. trends are in the direction that I believe they are taking.

Thinking in this area needs to take account of the fact that R. & D. engineers nowadays very commonly extend their training substantially beyond the conventional four-year term. A fairly large fraction of such engineers go directly into graduate school, and continuation through some sort of employer-sponsored part-time graduate study plan after the engineer is on the job is probably still more common. In either case the gap between the R. & D. engineer and a man in other engineering occupations is obviously widened, and their relative attitudes toward the purely undergraduate curriculum, which tends to become a foundation rather than an end in itself to the R. & D. man, are changed.

The Laboratories' principal undertaking in employer-sponsored graduate study is the so-called C.D.T. Program. I want to discuss it at some length, since it exemplifies many of the remarks I want to make on the mathematics curriculum. For the moment, however, I would like to turn to my own single excursion into undergraduate curriculum making.

There seems to be a merciful arrangement of nature which lets one block out completely from his conscious mind many juvenile mistakes and other traumatic experiences. I had been working on this talk for quite a while before it came to me that in a sense it was ground I'd already traveled over, that, in fact, I'd actually written a paper on mathematical education for electrical engineers —written it in the thirties. It had dropped completely out of my mind, but the memory did come back, and I had the rather wry experience of looking the paper over a few days ago to see what I thought some 25 or so years ago. I won't tell you exactly when and where the paper appeared, as I still have my pride, but I think it would be helpful to quote a bit from it and discuss it. It illustrates what seems to me to be in the long run the core of the curriculum construction problem, whether one is dealing with the undergraduate curriculum or with something like a C.D.T. Program.

The paper is in effect a plea to place the emphasis in engineering education on scientific fundamentals rather than on the mastery of detailed techniques. To quote some key sentences, "With technological progress proceeding at such a rate the case for a specific training for immediate results becomes more and more doubtful. The engineer's salvation must lie primarily in a fundamental scientific training, both because technological advances are increasingly based on pure science and because without such training he cannot keep abreast of technical advances during his working lifetime. As applied to mathematics, this means that the engineer's training should be as rich and diversified as possible. It should offer a ready gateway to any additional preparation which may be needed. In particular, it should emphasize general mathematical principles and methods of analysis rather than dexterity in a few specified fields."

I doubt whether anyone nowadays, certainly anyone in this room, would challenge such sentiments, any more than he would challenge the sancity of motherhood or the American Way. I like to think that 25 years ago they were more worth saying, although I doubt whether they came to my audience with the shock of real novelty even then. At any rate my present interest stems from the question how starting from such an unimpeachable general premise I managed to reach such a dubious particular conclusion.

To begin with, the paper made the point that the engineering curriculum was already overstuffed, and that it was pretty hard to put anything more in it. Using the figure of speech of a small suitcase being packed for a long trip (i.e., a man's career), it was hard to find enough to leave out in order to get the essentials in, especially when one didn't know the ultimate destination of the trip. Of course, curricula always seem overstuffed, so that this is only to say that some problems are perennial.

Then I made quite a number of other points. For example, I made the point that the engineers probably didn't really need as much training in manipulation as they were given—that they didn't do as many problems in their professional careers in several years as they did in a few months in college. Accuracy and knowledge were important, but great dexterity was not important. The fundamental approach was certainly the one to be striven for.

Then I spoke in glowing terms of the growing complexity of electrical engineering technology. I can quote some of this: "The day is past when an electrical engineer was a man who had some common sense, and who knew that it takes two wires to make a complete circuit. There is now a vast and difficult technique; moreover, technological development is still proceeding, and television and super power systems which are in the research laboratories today are the staples of tomorrow. To see how rapidly such a development may take place, and how sweeping the departures in technical methods may be, we need merely review the history of radio."

The use of radio, by which I meant normal broadcast, as a yardstick of progress, nearly knocked me off my chair when I re-read the paper, and it took me some time to remember how long ago I had written it. I had a similar disconcerting experience in first reading Mark Twain's *A Connecticut Yankee in King Arthur's Court*. No doubt you remember the story which concerns a very ingenious Connecticut Yankee who is transferred to King Arthur's court by a miracle and turns medieval England topsy-turvy by the introduction of various nineteenth-century inventions. The plot involves a civil war, and the climactic scene in the book is the rescue of the Yankee and the King by the Knights of the Round Table who arrive in time because they come on bicycles. When I read that it seemed curiously anticlimactic after the big build-up which the author had attempted, and it took me some time to realize that the bicycle was really a technological high-water mark when Mark Twain wrote the story.

After my pseudo-climax about radio, the paper goes on to make the plea for fundamental rather than specific training which I read you earlier and then advances my own remedy. I'll quote it; it won't take long. "My own recommendation is that the entering freshman should be immediately introduced to a course in the theory and functions of a complex variable substantially similar to that usually taught to seniors and first-year graduate students. Naturally, his progress would be slower." When I reread that, I said to myself, "Well—naturally," and fell to wondering how the entering freshman would in fact make out, and whether he would possibly progress fast enough to satisfy the mathematical requirements of the rest of the curriculum. At the time the paper was written, however, I was evidently prepared to take such problems in stride.

The paper proceeds to point out that much of the mathematics normally presented in the early undergraduate years, such as the description of the elementary

transcendential functions, much analytic geometry and, of course, the calculus, can be worked into the framework of a course in function theory, frequently with considerable economy of logic. It is suggested that the treatment of the elementary functions might be approached through the ideas of series expansion and convergence. This last suggestion might have some additional interest at the present time, as a possible gateway also to computational ideas.

The principal argument I raised for this approach, however, was its particular appropriateness for electrical engineering. I pointed out that in a sense electrical engineering theory was just an exercise in the complex variable. Trigonometric and complex exponential functions are commonplace. Design theories involving such things as applications of the maximum modulus theorem, bilinear transformation of circles into circles, and things of that sort just drop out of the complex variable, whereas in the existing treatment they had to be ground out painfully in one special case after another. And I pointed out also that Fourier analysis, both series and integral, was a necessary basis of any communication theory, and this was an easy way to get at it.

This still sounds persuasive to me, and, of course, the approach is fundamental enough. Nevertheless, I felt certain as I re-read the paper that I could no longer endorse such an idea, and after a little thought I was able to isolate the reason. It is because the approach was a fundamental one but only for a certain brand of electrical engineering. It is well adapted to a certain class of lumped constant circuit problems which were very prominent at the time, but it is less appropriate for some other aspects of electrical engineering which are conspicuous in the present day.

Perhaps the most astonishing lack is the absence of any consideration of wave propagation in continuous media. I had forgotten that electrical engineering is not always confined to wires. This is the more surprising because much of the work which led a few years later to the microwave revolution was going on around me at the time. Of course, an initial effort in function theory does not by any means foreclose later work in partial differential equations and boundary value problems, but it is hardly the most direct path either.

The next obvious omission is the lack of any specific consideration of the mathematics necessary to support subsequent courses in physics. Solid-state physics, in particular, is now so important to electrical engineering that any really fundamental approach to the electrical engineering curriculum would surely give consideration to the extent to which one might hope to give the engineer an understanding of the basic science underlying the new devices. The quantum-mechanical revolution which led to the new solid state field was well established when I wrote my paper, and some basic work in the solid state was already going on, but the fact that it might have eventual implications for electrical engineering was not obvious. At least, I didn't see them.

From the point of view of overall electrical engineering theory, the final lack is the most serious of all, although it probably would have been even more difficult to forecast. This is the absence of any sort of groundwork suitable for the digital revolution which was shortly to overtake electrical engineering. By "digital" I am, of course, referring to anything, such as pulse transmission, signalling codes, switching, or digital computers, which is based essentially on the consideration of discrete states. A "fundamental" approach to these matters might involve such things as parts of abstract algebra and logic, combinatorics, and possibly some of the classic demonstrations in Cantor's theory of sets. An approach simply through complex function theory, with its extreme emphasis on continuity and good analytic behaviour, leans as far as possible the other way. The revolution which was to come would have caught anyone trained strictly in the way I recommended flat-footed. Perhaps it is as well that I didn't make any converts.

The moral I am trying to draw from all this is that it is not enough merely to reject a specific, trades-school type of engineering education in favor of a more fundamental approach rooted in the basic sciences. One has still to identify the probable long-term trends in his area of engineering in order to decide just which fundamental approach he should take. This is clearly a very difficult problem, particularly if one recognizes that even in the basic sciences themselves the accepted "fundamentals" may change with time. However, by thinking of the problem in these terms, particularly with the help of the perspective afforded by the logical structure of the basic sciences themselves, we are clearly doing the best we can.

C.D.T. Program

These general remarks evidently apply to the graduate as well as the undergraduate curriculum. To illustrate them, I would like to turn to the Laboratories' so-called C.D.T. Program, which I mentioned earlier. The C.D.T. Program was not formulated in terms of this specific outlook, so that the illustration is by no means perfect, but it nevertheless shows the interplay of many of the factors I have mentioned. Of course, it also gives some specific indications of the sort of curriculum content we would now think desirable.

The history of the program is as follows: Shortly after the war, Bell Laboratories decided that a four-year education in engineering was not quite enough of a springboard for the people that we then wanted to recruit—that the recruits needed a running start in more advanced technology. We, therefore, instituted what we called a Communications Development Training Program, the C.D.T. Program. It had a somewhat mixed career thereafter.

We began by teaching the program ourselves, with emphasis on rather specialized material. In other words, we were concerned primarily with technologies which we practiced ourselves but which hadn't found their way into universities either because they were new or, more usually, because of their specialized nature. The texts turned out to be a tremendous mass of material, because the authors were all very enthusiastic about their specialties and wrote and wrote and wrote. The poor devils who had to take the work were really snowed under. But they stood up to it manfully, and, I suppose, learned something. At least they survived, and most of them have done very well with us since.

This, of course, was an example of the specific type of engineering education about which I had been so disparaging in my earlier paper. However, there is no logical inconsistency here. One of the principal points in my paper had been that major industrial employers, at least, could be relied on to teach their own specific technologies, if necessary, but that an opportunity once lost to teach the fundamentals in the proper way was gone forever. Nevertheless, the Laboratories decided after a few years' experience that we were mistaken, even in our own framework, in giving quite so much emphasis to specific technology. We therefore reoriented the program much more toward physics and mathematics. There was still specialized material, but the emphasis on a more fundamental approach was clear.

We taught this also ourselves for a few years, until the job became too burdensome, and we enlisted the help of New York University to teach first a few courses, and then more. At the present time, they have a branch in our own quarters in New Jersey, and teach most of the material. Since our original return to a more fundamental orientation, there has been a steady, if gradual, further evolution of the curriculum, partly to accommodate N.Y.U.'s ideas of the course structure they were prepared to support and partly to reflect our own developing understanding of the probable future of communications engineering. I hope that a brief account of the present state of the program will be interesting to you. As you will see, the program has had a history of evolution and thus represents, on a sort of trial-and-error basis, our

opinion of what the engineers we hire ought to have been taught that they don't normally get.

The complete course is done on the company's time, and at full salary. It takes up three days a week for one year; two days a week for the next year; and one day a week for the third year, so that all told it is fairly ambitious. The total instruction amounts to 52 semester hours, according to normal bookkeeping. Of this, 36 to 42 hours are taught by New York University, and academic credit is received for them. Thirty-six points is New York University's minimum for a master's degree, and the courses are so selected that a master's degree is the normal outcome. The remaining 10 to 16 points represent special technologies which we teach ourselves. I think they are comparable in level of difficulty to the rest of the work. As a matter of fact, we usually teach them after N.Y.U. finishes and rely on the foundation which has been laid by N.Y.U. for these courses.

I don't, unfortunately, have here the announcement of the complete program, but Table 1 shows the courses which are probably of most interest to you. As in any university, there is a distinction between the 100 series courses, at the beginning graduate level, and the 200 courses, which are supposed to be at a more advanced level. The course titles are New York University's own and may require a little explanation.

TABLE 1

E. E. PROGRAM

Math B76-B86—
Advanced Calculus (no credits)
Math 207E—
Functions of a Real Variable
Math 208E—
Functions of a Complex Variable
Math 131E—
Probability and Statistics in Engineering
Math 224E—
Time Series
Phys 101E—
Introduction to Theoretical Physics
EE 274—
Logic and Switching

The first item, Mathematics B76 and B86, is not taught for credit. It represents about a third-year undergraduate level mathematics course assumed as a prerequisite for the graduate level work of the program proper. It is taught as a make-up short course in the summer preceding this program for the benefit of those of our recruits who need it. I might mention in passing that there are two other deficiencies in undergradute preparation which occur often enough to require similar make-up short courses before the main program begins. One is in simple electric circuit theory. This deficiency would hardly exist if all our recruits were electrical engineers. Some of them, however, come from other areas such as physics which may leave them with a good enough primary background, but with some particular deficiencies for graduate engineering work. In general, we welcome such recruits. The other principal make-up course is in elementary microwave theory, which is postulated for the rest of the program but which turns out not to be in all undergraduate curricula. You will recall the remarks I made on this subject in reviewing the deficiencies of my own foray in curriculum making.

Listed on the remaining lines of Table 1 are the graduate level courses which are essentially mathematics, by content if not by title. Most of them, however, are taught in the college of engineering (the letter E is supposed to signify this), rather than in the college of arts and sciences, and reflect a corresponding difference in emphasis. Thus Mathematics 207E, "Functions of a Real Variable," is much less rigorous and much closer to a sort of advanced calculus course than it would be in a pure mathematics sequence. The title of Physics 101E, "Introduction to Theoretical Physics," is a similar misnomer. It actually stands for a course primarily directed to vibrations and waves and similar boundary value problems. On the other hand, Mathematics 208E is a pretty straightforward complex variable course. It reflects our conviction that for the classical parts of electrical engineering, at least, this is the most fundamental mathematics.

Mathematics 131E, "Probability and Statistics in Engineering," is introduced

for the same broad reasons which motivated the CUPM panel to suggest trying to bring at least some probability and statistics in at the undergraduate level. It is key material for many engineering situations. (I might add, in passing, that I also advocated it, in addition to the complex variable, in the paper I quoted earlier.) Mathematics 131E also serves as the first part of a two-course sequence, the second member being Mathematics 224E, "Time Series." Those of you who know modern communication theory will recognize, of course, that the time series work is directly preparatory to signal analysis and information theory. Information theory proper we still teach ourselves as one of the special technologies in the third year. I might say as an interesting sidelight that engineers who don't understand probability sure don't. The probability and statistics sequence is usually either the easiest or the hardest part of the program, depending on the student.

The final course, EE274, "Logic and Switching," is a general introduction to what I referred to earlier as the "digital" field. It is supposed to provide a foundation for the analysis of discrete circuits and discrete operations, whether used in switching, computers, signalling or what not.

The courses listed in Table 1 represent about half of the work which the typical C.D.T. student takes in N.Y.U.'s part of the C.D.T. Program. The remaining half includes one or two courses in physics, because of the importance of solid state physics to modern electrical engineering. The rest of the curriculum is in electrical engineering proper. It includes work in such fields as linear circuit theory, amplifier design, control systems, advanced microwave theory, transient analysis, and so on. The list of courses is fairly large because this part of the C.D.T. Program admits a number of options. Whichever option is taken, however, the work tends to be heavy, with a very strong theoretical flavor.

In addition to this main program for electrical engineers we have two alternative programs (which turn out to be very similar to one another) for recruits in mechanical engineering and engineering mechanics. About one-quarter of the entering students take one or another of these alternatives. The programs are on a somewhat lower level, mathematically, than the one the electrical engineers get. I have summarized the essential theoretical courses in Table 2. You will identify several of them from the E.E. sequence.

TABLE 2

M.E. & E.M. PROGRAM

Math 105E-106E—
Mathematics for Engineers
Math 131E—
Probability and Statistics in Engineering
EE 274—
Logic and Switching
Phys 101E—
Introduction to Theoretical Physics
EM 206—
Theoretical Mechanics

We are also experimenting with still other options which are intended to suit smaller numbers of people. The most interesting of these, for the purposes of this meeting, is the applied mathematics program, shown by Table 3. You will note that these are not "E" courses. In other words they are taught in the regular mathematics framework and are "purer" and perhaps heavier than counterpart courses in the engineering framework. The program normally leads to an M.A. in mathematics.

TABLE 3

APPLIED MATHEMATICS PROGRAM

Math 245-6—
Theory of Functions of a Complex Variable
Math 217-8—
Introduction to Probability-Statistical Inference
EE 274—
Logic and Switching

Five approved math. electives from M105-6, Numerical Methods; M107-8, Mathematical Machines; M111, 212, Linear Algebra; M213-4, Algebra; M243-4, Real Variables; M247-8, Ordinary Differential Equations; M279-80, Methods of Mathematical Physics; M224E, Time Series; M291, Linear Programming.

Where do the C.D.T. graduates go in our work? A few of them go into research, but on the whole the research area is peopled with Ph.D.'s in one of

the sciences. The usual destination of a C.D.T. graduate is one of our development areas. In telephone work this may include wire transmission and switching, radio transmission, component development, telephone instruments and outside plant. In each of these areas one is confronted by a spectrum of technologies, from the oldest and best-established arts to the most modern. The C.D.T. graduate may also go into one of our military development areas, where the subject matter may include data processing systems, radars, and a variety of special purpose sensing and communication devices.

We also do quite a bit of systems analysis, for both telephone and military work, and must rely in part on the C.D.T. program to staff this work also. These are probably the most difficult areas to fill properly. Systems analysis takes people with a certain versatility and a certain breadth of interest and knowledge, and it's rather difficult to get them. Engineers seem on the whole to be a little more specialized in their interests, as perhaps they should be. However, by proper selection and by relying rather heavily on the slightly "off-beat" programs, such as the applied mathematics sequence, we are able to make out.

We are still tinkering with the program; there are still some difficulties. One is the heterogeneity of the input. The graduates of the various engineering schools in the country differ far more in what they actually know than a casual persual of academic announcements would lead one to expect. Another factor which bothers us a good deal is the converse of this—it's the homogeneity of the output. Too many of our engineers are now put through what seems to be the same mill. One wonders if an R. & D. organization with a little more variety wouldn't really be better. This is one of the reasons underlying our efforts to introduce more options into the program. Another problem is that of choosing the best point of balance in the eternal seesaw between training in specific technologies, albeit at an advanced level, and a more fundamental approach. As we introduce more optional sequences we also tend in the long run to give more weight to specifics.

Nevertheless, we are quite well satisfied with the C.D.T. Program, on the whole. There is no doubt that our new recruits who have pursued this sort of education are much more capable on the average than the engineers whom we recruited in the past. They are better prepared for the problems we really need them for. They can dig more deeply and begin to play a responsible technical role more quickly.

The actual content of the curriculum is, of course, responsible in part for this increase in effectiveness, but some of the reasons are indirect. For example, since we know what's before the men, we can double-check their undergraduate records to determine whether they are likely to survive the program. In principle, this doesn't change our recruiting standards, but in practice I suspect that it makes us more discriminating. Another factor which is quite important is that the men tend to take themselves more seriously than they otherwise might. The existence of the C.D.T. Program shows how important we regard the men's careers to be, and they tend to set higher standards for themselves accordingly.

This brings me to my final point. At one time incoming engineering recruits, whether for the Laboratories or elsewhere in industry, were treated pretty casually. The newcomer was usually assigned directly to some work group and expected to make any further gains in competence by a haphazard informal apprenticeship. The fact that we can no longer treat new engineers so casually is simply one reflection of a general upgrading of the engineering profession which appears to be one of the conspicuous trends of our times. The engineer is worth more, his salary level is higher, and, as the C.D.T. Program suggests, the expected standard of formal academic preparation is also going up.

This can be stated in another way. An R. & D. engineer at the present time is fenced in between two kinds of people. On the one side is the Ph.D. in science whom we all recognize. On the other side is a man you may not have thought

so much about. He is the product of a technical institute, a subprofessional, the technical or engineering aide. The Laboratories actually employ each year almost as many graduates of technical institutes in this engineering-aide capacity as we do full-fledged engineers who go through the C.D.T. Program.

The number of technical institutes is growing. They grew very fast after the war under the G.I. Bill. The standards are also improving, and may surprise you. Our neighbor, the R.C.A. Institute, is a good illustration. We employ several dozen of their graduates as technical aides every year. They offer courses on various levels, lasting from one year up. Their fundamental electronics technology program, with which we are particularly concerned, lasts 27 months, or about 3 academic years, when pursued on a full-time basis. The content of the program does indeed seem to be almost equivalent to three academic years' work, as that might be understood in an engineering school, but the distribution is a bit lopsided. The course is about 60 per cent electricity, 30 odd per cent mathematics and science, 4 per cent English and technical writing and 2 per cent everything else.

Table 4 lists the mathematics courses which are given in the electronics program. The first items, M-11, M-12, and M-13, are reviews of secondary school algebra, geometry and trigonometry and thus are in a certain sense "non-credit," but the remaining items seem to be at college level. Thus the calculus sequence is said to include plane and solid analytic geometry, differential and integral calculus, and some further topics, such as complex algebra, hyperbolic functions, and elements of differential equations, of particular interest in electrical engineering.

TABLE 4

RCA INSTITUTE

M-11, M-12, M-13—
Review of Algebra, Geometry, Trigonometry

M-21—
Advanced Algebra

M-22, M-31, M-41, M-51—
Calculus I, II, III, IV

Even if some of this work is not very thorough, it still represents a mathematical coverage about as extensive as a well-trained electrical engineer might have had a generation or so ago. It is thus substantial, in a sense. If we assume that a similar statement might be made in other technical areas, it means that well-trained technical aides are qualified for many of the jobs that were actually filled by graduate engineers in those days. To compete successfully the graduate engineer must shift to higher ground. He needs to be closer to the Ph.D. and not so close to the well-trained technical aide, or the old-fashioned engineer. This is what we are trying to manage in our C.D.T. Program.

Conclusion

What is engineering coming to? This is a question I raised earlier in the paper, and tried to point out that it needed answering before one could plan an engineering curriculum with real assurance. It is not a question I feel capable of answering very adequately, but perhaps a few general comments may not be amiss.

In the first place, engineering is certainly coming to be a more substantial profession than ever before. World forces—the competition of the cold war, the problems of the undeveloped countries, the general pace of scientific and technical advance — are all tending to bring engineering up. The things I have touched on—the lengthening of professional education for R. & D. engineers to five or six years, the shift from specific courses capable of immediate application to more fundamental courses, the growth of a sub-professional group capable of doing many of the things engineers used to do—are all indications of this trend.

In the second place, engineering is more closely tied to pure science than it ever was before. It is a platitude today that there is a scientific revolution in our times. It is not so generally realized that this also means an engineering revolution, because the engineer is the man who makes something of scientific advances. So engineering is as important as scientific

progress. Thus it is often said that a missile launching is either a scientific success or an engineering failure. In fact, as Keith Glennan used to say over and over when he was head of N.A.S.A., it's all engineering. Perhaps the instrumentation in a space probe can be called science but the rest is just an engineering exercise. What is really distinctive about our age is the fact that we have become so aware of the practical values in scientific knowledge. Thus, organized engineering effort tends to tread immediately on the heels of any scientific advance, whether in electronics, chemistry, aeronautics, or what not.

The engineer must, then, do the job of making scientific advances work. In the long run, he is a designer. He is the man who puts things together into a pattern. He is in that sense a creator, rather than an analyst. This is very obvious in electronics, where a single system may contain thousands and perhaps millions of very small parts which are all put together in a pattern to serve some common purpose, as deliberately as bricks are put together to make a building.

The guiding ideas in such a creation are necessarily theoretical. The bricks which the electronics designer uses are bricks which are theoretically convenient. In other words, the devices and elements which the engineer uses are those with simple enough mathematical properties to be readily understood, alone or in combination with others. Similarly, the over-all pattern must have logical regularities which make it capable of analysis. The theoretical structure in the long run precedes the rest of the design and gives the engineer (who may not always realize it) his ideas.

So, the engineer must understand his field basically through its theoretical structure, and he must somehow have a perspective on technical advance. He is not necessarily a research-minded man, but he must be able to grasp the implications of scientific advance for his area. He must know how to learn new things when he needs them, since we can't teach him everything at once. He must understand planning to undertake design work at all, and he must understand abstraction to undertake design work of great scope or difficulty. Actual situations are usually too complicated to be readily understood in terms of their exact structure. They need to be simplified, to be abstracted, in other words. One must make a mathematical model which can be played with, which can be explored by analysis or computation. Finally, of course, one must establish that the simplifications which were made are not critical. This sort of process may go on quite casually in simple situations, or quite formally, as in complex electronic systems, but in one way or another it lies at the heart of the design process.

What does this mean for the mathematics of engineering? It obviously means a great deal, if only because an approach to engineering through its basic theoretical structure necessarily requires a substantial mathematical preparation. However, in stressing the nature of the design process, especially for complex systems, I was trying to imply more than this. I used the words "mathematical model" and "abstraction" deliberately, because the process is something like the one a mathematician follows in building a logical edifice. He finds a set of relations he can work with, sets them up, and sees what happens. In particular, it is like the work of an applied mathematician who, like an engineer and unlike a pure mathematician, must go through the final step of establishing an adequate correspondence with the real world. In a sense, of course, the same pattern is followed by exploratory thinking in any field, but it seems to find its most natural embodiment in mathematics.

As engineering becomes more complex and at the same time accelerates its progress, it is inevitable that emphasis must shift more and more toward formal intellectual tools adapted to the exploration of new situations and away from concrete subject matter and particular established techniques. This makes mathematics more and more a natural focus for the engineering curriculum; I hope that the members of the mathematics fraternity will accept the challenge.

Analysis, Synthesis, and Optimization in a Design Oriented Curriculum

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Five years ago the U.C.L.A. Department of Engineering began a comprehensive study of engineering and engineering education. A year ago the program was accelerated by a $1,200,000 five-year grant from the Ford Foundation. Since we are in the midst of a continuing program, this article on the analytical content of the U.C.L.A. unified engineering curriculum must be taken out of the context of an extensive experiment in engineering education. Also, it must be considered as a progress report on a curriculum which can be expected to change considerably in the next four years. Although the account of our activities to date is intended to be quite factual, the reader should realize that the future details of the program will be decided by our staff. Therefore the conclusions and projections noted here do not necessarily represent the views of the University of California Regents, the U.C.L.A. Department of Engineering, or perhaps any staff member other than the author.

Before reviewing our past and present experiments with the content of our undergraduate curriculum, several remarks describing the background of the program are in order. The U.C.L.A. Department of Engineering under the direction of Dean Boelter offers a single, unified, 140 unit undergraduate curriculum. Of the 140 units, there are 18 to 21 units of technical electives. The department is also unified, i.e., not divided into the conventional branches, civil, mechanical, electrical, etc. Without the barriers of traditional departmentalization it offers unusual opportunity for inter-disciplinary activities.

In order to get on with the curriculum undertaking our staff has had to answer a number of questions. These have concerned the need for change, the alternatives open, and the manner in which new material was to be selected and old material discarded. The need for the curriculum development is believed to lie in the exponentially increasing fund of technical knowledge. For many years the facilities for organizing and interrelating knowledge have been falling behind our ability to generate new information. Furthermore, a haphazard addition of courses to the existing curriculum or a fifth year of study does not present an appealing or practical answer to the dilemma of the undergraduate engineering curriculum. In what can be considered an act of faith, our staff has concluded that new curricular material can and must be introduced either by effecting economies in the organization of existing material or by the elimination of old subject matter that is not as useful as the new.[1] As an aid to course-content decision-making, three selection criteria have been adopted; these are:

1. Relevance to Engineering
2. Generality
3. Articulation

[1] We have been encouraged by the efforts of Dartmouth's Professor Kemeny in this direction.

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As a further guide for course organization, the staff has decided that, "Courses should be organized in accordance with the unification provided by the supporting sciences and mathematics. The engineering curriculum should emphasize concepts which will be of value long after graduation."

An engineering education is believed to be built upon the three foundations of engineering, humanities, and science. The U.C.L.A. Engineering Department considers design to be the essence of engineering. Our present studies concern the seven-year engineering program ending at the doctorate. In this program throughout the seven years, emphasis is to be placed upon engineering design, including graduate research on design and the design process. Although many of the aspects of the undergraduate program have yet to be explored, it seems reasonable to consider that it will unfold the design process to the student. His undergraduate design experiences will be given him through the design of components and subsystems.[2] At the graduate level his design tools will be sharpened with a substantial portion of the doctoral candidates expected to concentrate on the problems of large-scale systems design.

Present Curriculum

These days, change is the norm for engineering curricula. We regard our existing undergraduate courses in mathematics and engineering analysis and synthesis as representing an interim phase of development. Five semesters of mathematics (given by the mathematics department) are required. These begin with five units of calculus with analytical geometry. The remaining four semesters each contain three units. The fourth semester introduces ordinary differential equations including the Laplace Transform. The fifth semester is devoted entirely to functions of several variables (including Lagrange multipliers), vectors, and vector field theory.

[2] We recognize that the words "component," "subsystem," "large scale system," are only relative and do not convey a precise meaning.

The relationships among engineering analysis, synthesis and optimization and their supporting mathematics are always interesting. The problem of engineering education in this area can be understood by considering the circumstances that the practicing engineer will meet. He never analyzes in its entirety any physical entity no matter how simple, for in fact, no system is in reality truly simple. Instead he discards what he hopes are the less essential elements of his system until he has reduced it to a model that he can represent in words, graphs, symbols or figures. He further continues to simplify the system until he has brought it to a state where his analytical tools will enable him to manipulate the model to give answers to the problem before him. The engineer of necessity will categorize his analytical tools in terms of the models these tools will manipulate rather than in the conventional mathematical ordering. To date I have been able to identify only a very limited number of models or combinations thereof which can represent systems that we are able to analyze satisfactorily. These are:

1. Linear Lumped Constant Model
2. Linear Distributed Parameter Model
3. Nonlinear Model
   a. Lumped Parameter
   b. Distributed Parameter
4. Arrays of Discrete Elements and States (Statistical Model)

The first of the preceding represents probably the simplest model that the engineer can treat. His tools here are ordinary differential equations including matrices, complex variables and the Laplace Transform. To introduce the student to linear, lumped constant systems, the U.C.L.A. Department of Engineering requires three units of linear circuit analysis during the fifth semester (1st semester junior year). The course develops the linear, lumped constant mode of analysis for mechanical, thermal, acoustical, etc., systems as well as the electrical. The course builds on the fourth semester mathematics which presented ordinary differential equations through the Laplace

Transform. Matrix algebra is taught in the course and complex algebra is used extensively.

A course in linear, distributed parameter systems was introduced into our required curriculum three years ago. In the sixth semester the traditional offering in rotating electrical machinery was replaced with a unified[3] field theory course that builds upon the fifth semester of mathematics.[4] The new offering endeavors to give the student skill in translating data and experiences involving a wide variety of distributed parameter systems into the suitable field representation. A special effort is made to cause the student to become aware of the process of going from a specific experiment to the general field representation and then applying the generalization to problems from other areas. Some eight techniques for the exact or approximate solution of Laplace's Equation are presented. It is recognized that all of the first three models are simplifications of 3 b. An elementary treatment of separation of variables is included that illustrates the method and the physical configurations that yield to this approach. Since the conditions for a two-dimensional, solenoidal, irrotational field lead so easily to the Cauchy-Riemann conditions we have been concluding the semester with an introduction to complex variables and conformal mapping.

As one of the initial steps in preparing the student to deal with systems of discrete elements, an elective three-unit sophomore course in probability and statistics is being offered this semester by the Engineering Department. The course will cover the basic elements of probability and statistics through the law of large numbers, sampling, statistical estimation, least squares, regression and correlation, and the estimates of variance. For the next several semeters we will evaluate this offering, the courses which will depend upon it, and the elements of probability and statistics now being introduced into other courses. By the end of this period it is expected that any necessary additional changes will be instituted to insure that probability and statistics are fully integrated into the required curriculum. It is possible that the integration of the course within the lower division mathematics might be desirable either as part of the present sequence or as part of a parallel finite mathematics stem.

We believe that engineering design is an *inductive* process. What is done at the later stages depends upon what is learned at the preceding stages of the design process. Most courses in engineering are taught as though engineering is an exercise in *deductive* logic. The result has been an overemphasis on the analysis of existing (or proposed) systems and a vague, intuitive approach to problems of synthesis (or, more popularly "creative endeavors"). Recently our two-semester, junior-year course in thermodynamics has been completely recast to also emphasize the *inductive* rather than *deductive* aspects. The course begins with a development of statistical inference based upon Bayes' theorem. The Shannon expression for entropy is derived. It is shown how the assignment of probability distributions in such a way as to be consistent with the given data but maximizing the uncertainty (entropy) leads to statistical mechanics. Classical (deterministic) thermodynamical laws and theorems are seen to be the result of this "information theory" approach. Applications include the treatment of quantum effects in diatomic gases, the Debye solid, electron emission and noise (fluctuations). Although the course is labeled "thermodynamics," every opportunity is taken to illustrate applications in design. For example, the use of Lagrangian multipliers in optimization and the use of information theory as an aid to decision making are developed more fully than would be justified for the thermodynamics alone.

The pedagogical economics of these three junior-year courses are elementary. The linear analysis course introduces the linear, lumped constant model for all en-

[3] Unified in the U.C.L.A. (not Einsteinian) sense.

[4] See for example Sokolnikoff and Redheffer, *Mathematics of Physics and Modern Engineering* (McGraw Hill Book Co., New York), Chapters 3, 4, and 5.

gineering disciplines. Distributed parameter models and the analytical tools to handle systems through Laplace's and Poisson's equations are explored in the field theory course. Probability and statistics are well exercised and used as a basis for thermodynamics in the course in that subject. At the same time a foundation is laid for a number of other subjects including properties of materials and design.

Design and its supporting disciplines have been made the subject of an intensive study by our design sub-committee. Unified design courses are being presented in the second and seventh semesters. Freshman design explores the design process in some detail. The course lectures deal with the anatomy and morphology of design, computers, logic circuits, probability and statistics, communications, linear programming and other optimizing techniques. The place of the computer as an everyday engineering tool has been apparent for some time. Our staff believes that the student early in his training must have first-hand familiarity with the modern computer and its problem-solving potential. The first three lectures of freshman design introduce the student to the Bendix G15 Intercom 1000 computer program. Each student is expected to program and operate the machine before the end of the semester. Boolean algebra, Venn diagrams, and truth tables are taught and illustrated with simple diode logic circuits. The axioms of inductive logic (Bayes' theorem) and Shannon's formula for uncertainty (information) are given. With the elements of probability, loss functions, expectation, and strategy, the elements of decision theory are presented. The lectures on linear programming provide an early consideration of the optimizing problem. Communication, including the use of graphics and the English language, is introduced by a simple treatment of information theory. Here information theory is utilized to develop the concepts fundamental to all communications. It is evident, of course, that a respectable percentage of the lectures in freshman design are devoted to finite mathematics and, in fact, one of the texts of the course is *Introduction to Finite Mathematics* by Kemeny, Snell, and Thompson (Prentice-Hall, Inc.).

Our senior design course, which comes in the seventh semester, has been offered for the past four semesters. Its development has been particularly satisfying. Since it is only recently that the necessary background in probability and statistics has been introduced elsewhere, a treatment of probability and statistics is repeated in this senior course through sampling and stratification. Linear algebra is presented with convex sets, vector spaces, and matrix notation including diagonalization and inversion. Building on convex sets, decision theory is developed with Bayes' theorem, conditional probability, utility theory, notions of losses and regrets, and the economic justification of experiments. Game theory is offered to show the effect of competition on design. Game theory is carried far enough to develop the value of a game, notion of a saddle point, notion of utility in probabilistic terms and Von Neumann's lottery approach. Additional optimization techniques are introduced in the form of Lagrange's multipliers, elementary variational calculus, and the method of steepest descent for the computer. Linear programming is developed in matrix notation. The students are shown how to set up a linear program. A first introduction to dynamic programming is also included.

Since design is always concerned with value, engineers must be concerned with economics. This semester one of our staff has been experimenting with the content of the senior course in economics. In addition to the more conventional material and text (Grant and Ireson) he has introduced a new viewpoint using Chernoff and Moses', *Elementary Decision Theory*. The elements of game theory (two persons, zero sum) are given. Decision theory is related to economics and the basic notions of statistics and probability are introduced with minimax solutions and Bayes' strategies. Model and simulation studies are carried out through simplex solutions and an analysis of queues.

The Future

In predicting the future one usually extends from an interpretation of the past and present. Certainly our future course developments will often be outgrowths of our present activities. In changing curriculum content it is reasonable to expect to find some maximum rate at which students can master new material. It is also reasonable to look for this maximum, and then perhaps back off a little.

I believe that many of the frustrations of engineers during World War II can be traced directly to training which enabled them to analyze nothing more sophisticated than linear, lumped constant systems.

To properly serve the future, there is no question that the analytical foundations of engineering must be much broader. New and more general methods of synthesis and optimization must be introduced. Within five years I expect to find engineering schools turning out bachelors of science capable of setting up component and small system designs using any and all four of the principle engineering models. These men will understand the analytical techniques available for each model. They will not hesitate to use machines to obtain better answers than they could obtain unaided.

Course content will be articulated with the relevant mathematics being presented within a semester of its use. The luxury of presenting similar analytical techniques under different names in the various engineering specialties no longer will be afforded. Machine computation will tend to shift the emphasis from solution techniques to problem formulation. This enhanced preparation of the students will be obtained with few if any additional units of mathematics. In view of the press of additional material this last statement may seem somewhat contradictory. However, our experience to date has consistently shown that changing requirements and careful course selection does allow for substantial compression and revision. The improved mathematical background that the high schools will provide is a major factor that we must begin to consider in the near future. The efforts of the mathematicians to upgrade high school mathematics will soon begin to bear fruit. We in engineering education should be prepared to exploit this opportunity.

At U.C.L.A. we are beginning a second iteration in our studies of the analytical portion of the undergraduate curriculum. The existing required courses in mathematics are being reviewed to find room for finite mathematics. The effect of the computer upon both lower division mathematics and engineering design is under study. Our single required course in linear, lumped constant analysis is very crowded. A second semester would allow the introduction of active components, feedback analysis, and the elements of circuit synthesis. This would serve as a further base for the design stem, because then circuit techniques of realizability could be introduced along with the linear transfer function optimization techniques which have been developed in the automatic controls field.

The interdisciplinary teaching economies that can be derived from the distributed parameter (continuous media) model are extremely tempting. Starting from field theory with Laplace's and Poisson's equations, much of engineering (and science) has been traversed after the diffusion, wave, and biharmonic equations have been developed along with their general applications and modifications. As a second step toward developing a "continuous media" sequence, we have experimented for one semester with the possibility of replacing our traditional fluid mechanics course with a sixth semester offering in transport phenomena a la Bird, Stewart, and Lightfoot.[5] (Much of classical incompressible hydrodynamics is already presented in our field theory course.) The analytical tools of the course are fairly extensive, including in addition to ordinary differential equations and series expansion such material as vector analysis, partial differential equations, tensor notation, perturbation methods, Bessel functions, Gamma functions, and

[5] *Transport Phenomena* (John Wiley and Sons, Inc., New York, 1960).

complex variables. Student reaction has been favorable and the instructor was enthusiastic. However, a number of our staff have expressed reservations about the change unless steps are taken to preserve certain undergraduate experiences that are somewhat unique to fluid mechanics. They point out that in many areas of engineering and particularly in fluid mechanics, the effects of energy consuming interactions and non-linearities are often great enough to render meaningless a purely analytical solution. Here in general lies, as we all know, a fundamental danger to the essentially analytical presentation. The engineer must develop a reasonably accurate model of the real physical system. If his idealizations are too great, the loss of accuracy will more than outweigh any gain in analytical elegance. Several answers to this problem and to the future of the continuous media suggest themselves. There is need for a broader knowledge of nonlinear analysis. Also, our laboratories can do a much better job of developing an understanding of the role of empirical data. We intend to explore the problem further since on the other hand a knowledge of the fundamental mechanism of a phenomenon will usually offer insight into the empirical relations that should be sought in the laboratory.

Although our core curriculum changes of the past several years now prepare our undergraduates to handle three of the four major analytical models, our core curriculum does not yet include nonlinear analysis. It is interesting that this curricular need is still so strong today in spite of the fact that a major percentage of the useful characteristics of electronic amplifiers and other important devices depend upon the nonlinear characteristics of their materials or structure. A major effort should be mounted to organize the place of nonlinear analysis in undergraduate curricula. Fortunately the research in nonlinear systems during the past five years does offer hope for better understanding of the problem. It should be possible to generalize and unify the work that has been done in such things as piece-wise linear electronic circuits, self-adaptive control systems and nonlinear theory of deformable media. Analogue and digital computers are already proving extremely useful and may provide a large percentage of the answer to the nonlinear analysis problem.

Conclusions

It is always necessary at regular intervals to review the significance of what has been accomplished and the implications of what is proposed. In the foregoing material it should be evident that the analytical content of our undergraduate curriculum has been extended. At the same time there has been a de-emphasis of the traditional electrical, mechanical, chemical, industrial, etc., specialties. With this we have had to ask ourselves if these changes would not warrant shifting all of the instruction and, of course, all of the students into mathematics, physics, or an applied physics department. If our concern were only with analysis and sciences, this question could be difficult to answer in the negative. It would be, "Sure, get rid of them."

But engineering does have design as its major function. Design has been defined as "an iterative decision making progress to develop systems to optimize the value of resources." This great need for the extension of analysis into synthesis and then to optimization is distinctive of engineering. Within the last ten years the tools have become available to allow us for perhaps the first time to develop a coherent presentation of synthesis and optimization. The digital computer takes over the drudgery of iterative computation and makes economical an extensive search for an optimum.

With design as a decision-making process, the need for an understanding of decision theory is clear. Design (and therefore engineering) is an exercise in statistical inference. Engineers do not deal with deterministic systems. All engineering efforts of any significance involve payoff functions whose solutions depend upon a set of values derived from our society. In design we seek to deter-

TABLE 1

SCHEDULE OF COURSES DISCUSSED

Semesters					
I	Analytical Geometry & Calculus Math. 5 units	Finite Math.* Engr. or Math. 2 units			
II	Analytical Geometry & Calculus Math. 3 units				Design Engr. 3 units
III	Calculus Math. 3 units				Design* Engr. 3 units
IV	Calculus (Differential Equations) Math. 3 units	Probability & ** Statistics Engr. or Math. 3 units			
V	Vector Field Theory Math. 3 units	Linear Lumped Constant Systems Engr. 3 units		Discrete Systems Thermodynamics: Engr. 3 units	
VI	Linear Lumped Constant* Systems Engr. 3 units	Distributed Parameter Systems Field Theory Engr. 3 units	Distributed** Parameter Systems Rate Processes Engr. 3 units	Discrete Systems Thermodynamics: Engr. 3 units	
VII		Nonlinear Systems* Engr. 3 units		Economics Engr. 3 units	Design Engr. 3 units
VIII					Design* Engr. 3 units

* Proposed experimental courses
** Existing experimental courses
All others: Existing required courses

mine those answers which afford the highest probability of success.

To extend and further formalize the role of design in engineering we have funded what we expect and finally hope will be a comprehensive study and research program. We are adding staff to man six specific research activities.

These concern:

1. Synthesis techniques
2. Optimization techniques
3. Decision making in design
4. Design with computers
5. Criteria development and value systems
6. Information organization and transmission.

From this research will come the understanding necessary for additional curriculum revision. In the synthesis and optimization studies we expect to find those methods which are applicable to all engineering design.

Interestingly enough our formal techniques for optimization seem at a first rather casual glance to have outstripped our methods for synthesis. If synthesis is considered to be complete when the requirement of realizability is satisfied, then general synthesis methods appear to be neither as numerous nor as elegant as the optimization procedures that follow once the realizability question is satisfied.

I believe, incidentally, that our original considerations of the academic ordering of the preparation for component and system design are changing. It had originally appeared that design education at the undergraduate level would concentrate on preparation for component design. In graduate school more advanced training would provide the methodology for large-scale system design. With additional study this picture has become blurred. Sophisticated techniques too often turn out to be just as useful for component design as for large system design. The model of even a simple component becomes increasingly complex as we allow ourselves to consider more of the component parameters. Intelligent design of a component also demands a comprehensive understanding of the system in which the component is embedded. I believe now that undergraduate emphasis upon component or subsystem design will be the result of the student's limited storehouse of experience rather than a consequence of course content.

In summarizing the program we have undertaken, our philosophy is seen to be rather simple and probably typical of engineering. We wish to apply to the problem of producing a modern curriculum all of the tools that engineering has at its command, to produce an educational process as efficient as any mechanical process we have yet designed. **We are essentially striving to optimize the four-year undergraduate experience.** We seek to develop those generalities that will give our students a foundation they can build upon during most of their professional life—to illustrate very early the entire structure of engineering so they will understand the rationale of their education as they receive it. As briefly mentioned previously I do not wish to see skill in English composition and graphics demanded without first fully revealing the underlying generalities and laws that govern all modes of communications—the meaning of coding systems, the limitations of human information channel capacity, the effects of all types of noise including grammatical errors and careless dimensioning. Instead of merely offering a set of skills we hope to show the need and the utility so that the students will seek to develop the skill themselves.

• Proposed experimental courses
•• Existing experimental courses
All others: Existing required courses

RAWE DEAN OF ALFRED TECH

Roger F. Rawe of Alfred has been appointed Dean of the State University Agricultural and Technical Institute at Alfred by President Walter C. Hinkle.

Mechanics Division Bulletin

EXECUTIVE COMMITTEE

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E. J. Marmo	1962	E. C. Clark	1964
F. P. Beer	1963	I. H. Shames	1964
D. C. Drucker	1963	W. D. Jordan	1965

*Division Representative on the General Council.

Secretary of the Mechanics Division: E. Russell Johnston, Jr., Department of Civil Engineering, Worcester Polytechnic Institute, Worcester, Massachusetts.

Editor: Arthur W. Davis, Department of Engineering Mechanics, Iowa State University, Ames, Iowa.

CHAIRMAN'S MESSAGE

It is a great pleasure to express my greetings to the membership of the Mechanics Division of ASEE. Those of you who attended the Lexington meeting, I am sure, would agree that we had an excellent program and that all of the speakers did an outstanding job in presenting their talks. It is gratifying to note the excellent attendance at our meetings. All this speaks well for the vigor of Mechanics and its teachers.

As a consequence of the Lexington meeting and subsequent actions, Professor W. D. Jordan of the University of Alabama has been added to the Executive Committee; Professor J. O. Smith of University of Illinois becomes our Division representative; Professor A. W. Davis of Iowa State University remains as our editor; Professor E. R. Johnston of Worcester Polytechnic Institute is our secretary. Professor Daniel C. Drucker of Brown University has been appointed the program chairman for 1961-1962.

It has been suggested that in the next year's program special consideration be given to the following themes: (1) nonlinear problems in mechanics, (2) joint sessions with civil and mechanical engineers emphasizing the tie of Mechanics to their respective areas, and (3) presentation of short technical papers in mechanics with pedagogical implications.

Your suggestions for papers for this program are welcome. In fact, the Mechanics Division welcomes all ideas and suggestions for the improvement of the services that our Division performs to the engineering teaching profession.

E. P. Popov
Professor of Civil Engineering
University of California
Berkeley, California

ELECTROMECHANICAL ENERGY CONVERSION

An all-day session discussing the teaching of Electromechanical Energy Conversion was held during the AIEE summer meeting, June 22, 1961, at Cornell University, Ithaca, New York. This session was jointly sponsored by the American Society for Engineering Education, the Institute of Radio Engineers, and the American Institute of Electrical Engineers.

Seven of the conference papers presented at this session have been printed as a single publication by the AIEE. Copies of this AIEE special publication, S-128, *Electromechanical Energy Conversion*, can be purchased from the Order Department, AIEE, 345 East 47th Street, New York 17, New York for $1.25 each.

Copies of the progress report of the Electrical Engineering Division's Committee to Survey the Teaching of Electromechanical Energy Conversion Courses, by Dr. A. D. Bailey, Conference Paper CP 61-832, also are available from AIEE while the supply lasts; the cost, per copy, is $0.50 to members of AIEE and $1.00 to nonmembers. A final report will be available later.

Retention of Physical and Geometrical Meaning in Vector Analysis

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Much attention is currently being directed to the use of vector algebra and vector calculus in the basic engineering mechanics courses. As an element in the evolutionary struggle to do an increasingly better job, this attention with its accompanying experimentation is a welcome trend. Our main problem is to achieve forward steps and minimize, at the same time, the unstable oscillations of emphasis which seem to characterize so much of what we do in this country. Currently we may observe examples of the "full vector treatment" where the vector notation is employed whether it offers distinct advantage or not. Indeed, it is implied from the apparent recent "rediscovery" of Gibbs' notation that vector quantities are now being analyzed for the first time.

Another observer has pointed out that the more mature treatments of mechanics by well-known European writers do not make a fetish of the use of vector notation, but merely employ it whenever it offers advantage. This is the more sensible point of view which we should adopt but which we have so far failed to achieve in this country. Vector notation is but a tool to facilitate the description of many vector relations. As such, the utmost caution is needed to prevent preoccupation with the manipulative aspects and symbolism of the notation from diverting primary attention from the physical, geometric, and engineering meaning of mechanics. We should not permit engineering mechanics to be used as an excuse for teaching a course in vector analysis. The distinction represents a fundamental point of view which calls for a review of basic objectives in order to lend perspective.

As an objective for our basic engineering mechanics course, the statement, "to teach the principles of mechanics," is wholly inadequate. The basic concepts and principles constitute the objective of the introductory course in physics. Instead, the objective of the engineering mechanics course should be the development of abilities to extend and apply concepts, principles, and methods which aid in the description of engineering systems involving force and motion. The distinction between these two objectives and points of view lies in the basic difference between engineering and science. Altogether too frequently do we find the course in engineering mechanics treated outside the context of engineering. Within the framework of engineering purpose and as a guide to the place and emphasis of the tool of vector notation in engineering mechanics, it is well to review the major steps which are basic to and characteristic of the treatment of an engineering problem in mechanics. First and foremost is the formulation of the problem which calls for the identification of knowns and unknowns, simplification through assumptions and approximations, separation of cause and effect, recognition of governing principles, and determination of the sequence of solution

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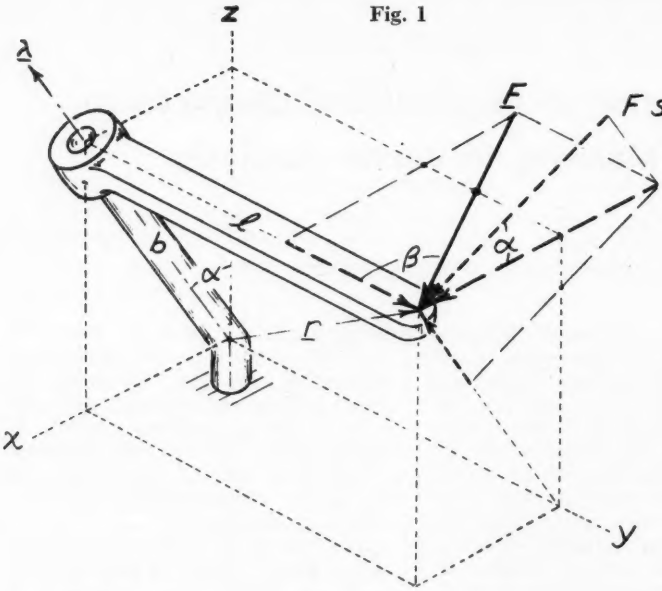
Fig. 1



$$M_\lambda = \underline{r} \times \underline{F} \cdot \underline{\lambda}$$

$$= \begin{vmatrix} r_x & r_y & r_z \\ F_x & F_y & F_z \\ \lambda_x & \lambda_y & \lambda_z \end{vmatrix} = \begin{vmatrix} b\sin\alpha & \ell & b\cos\alpha \\ F\sin\beta & F\cos\beta & 0 \\ \sin\alpha & 0 & \cos\alpha \end{vmatrix}$$

$$= Fb\sin\alpha\cos\alpha\cos\beta - Fb\cos\beta\sin\alpha\cos\alpha - F\ell\sin\beta\cos\alpha$$

$$= -F\ell\sin\beta\cos\alpha$$

through recognition of the dependence of one quantity upon another. The process of formulation of the problem is essentially the process of constructing the mathematical model. Once the ideal model is constructed, the actual process and technique of solution proceeds. The most interesting, difficult, and important phase of the entire process lies in the *formulation* of the problem. It is only through strong emphasis on this aspect of the total experience that the tools of analysis, including vector notation, are seen in their subordinate and supporting (yet important) roles. One of the greatest dangers we face is to resist the temptation to present mechanics with undue emphasis upon the solution of essentially preformulated problems where nothing is left except the bare procedure of carrying out the solution.

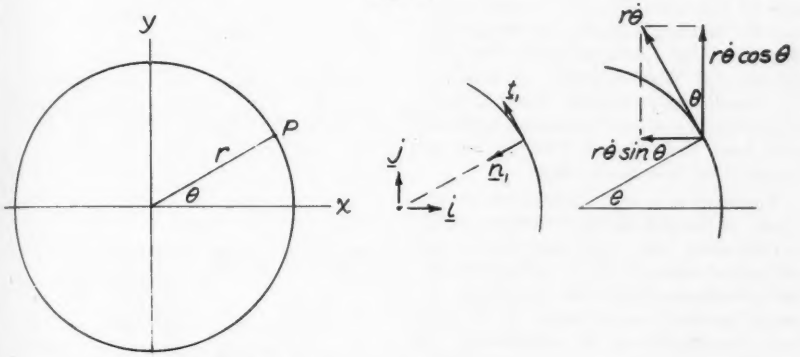
Anyone who is at all familiar with vector notation can hardly fail to appreciate its beauty and basic simplicity for the spatial description of vector quantities. With the perspective of engineering purpose in mind, it becomes clear that the physical and geometrical meaning of analysis by vector notation should form a strong base in the introduction of vector analysis in mechanics. Vectors are physical quantities with geometric properties, and it follows that the key to their understanding rests upon a base which permits the free transition of thought between

the physical situation and its geometrical representation. In one dimension there can hardly be any advantage ascribed to vector over scalar algebra. The use of moments and angular momentum for the description of plane motion, for instance, involves vectors which remain colinear, and no particular advantage to the use of the cross product and the unit vector normal to the motion plane is introduced.

In two dimensions vector algebra and the description of vector geometry with scalar notation are quite comparable. But in three dimensions, particularly with the addition of time dependence, the full power of vector notation becomes evident, and it is here that the vector tools should be stressed.

Several figures are offered by way of illustrating a few of the cautions, com-

Fig. 2



$$\underline{r} = r_x \underline{i} + r_y \underline{j}$$

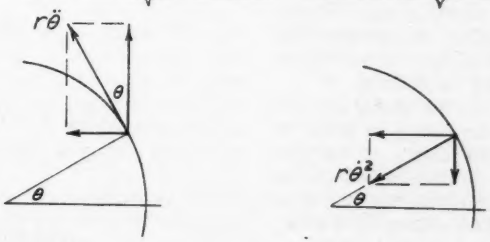
$$\underline{r} = r\cos\theta\, \underline{i} + r\sin\theta\, \underline{j}$$

$$\underline{v} = \dot{\underline{r}} = -r\dot{\theta}\sin\theta\, \underline{i} + r\dot{\theta}\cos\theta\, \underline{j}$$

$$= r\dot{\theta}\, \underline{t}_1$$

$$\underline{a} = \dot{\underline{v}} = \ddot{\underline{r}} = (-r\ddot{\theta}\sin\theta - r\dot{\theta}^2\cos\theta)\underline{i} + (r\ddot{\theta}\cos\theta - r\dot{\theta}^2\sin\theta)\underline{j}$$

$$= \underbrace{-r\ddot{\theta}\sin\theta\, \underline{i} + r\ddot{\theta}\cos\theta\, \underline{j}}\ \underbrace{- r\dot{\theta}^2\cos\theta\, \underline{i} - r\dot{\theta}^2\sin\theta\, \underline{j}}$$



$$\underline{a} = r\ddot{\theta}\, \underline{t}_1 + r\dot{\theta}^2 \underline{n}_1$$

parisons, and advantages of vector notation. In Figure 1 the evaluation of the moment of the force $\underline{F}$ about the axis of the bent shaft may be written in determinant form from the triple scalar product following the basic definition of moment as a cross product and its component as a dot product. The manipulation required, however, is apt to obscure the geometrical visualization of the component of F which produces the physical moment. With emphasis on the physical side of the problem, the current result can be written directly by inspection. Expression by vector notation does permit careful "bookkeeping," as someone has noted. But systematic accounting, as important as it is, becomes important only after the physical effect to be accounted for is entirely clear.

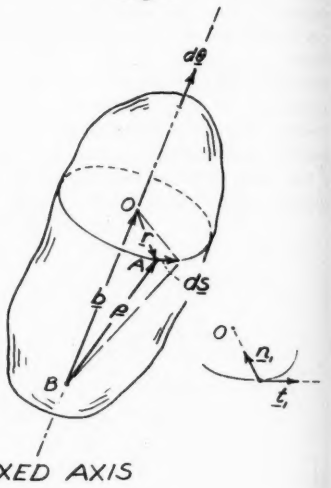
Figure 2 is a reproduction of an analysis of simple circular motion which is frequently seen. This approach is not advocated since it fails to utilize directly the advantage of the time derivative of a vector quantity and involves an unnecessary transformation of coordinates. At best it is merely an exercise in manipulation.

Figure 3 illustrates preferred presentations for circular motion, both vector and scalar. The advantages of this vector presentation are, first, that it portrays immediately the three-dimensional aspect of fixed-axis rotation of a rigid body and, second, that it deals with the natural coordinates for circular motion. The scalar analysis from the figure showing the geometry of the differential vector changes is probably a little shorter and more meaningful, physically, because the derivative of the vector is seen directly on the vector diagram. Experience indicates that the two analyses presented together are mutually reenforcing.

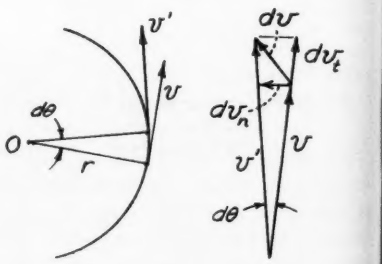
Figure 4 illustrates the similar analyses of plane curvilinear motion in polar coordinates. Here the clarity of the geometric picture is a distinct aid to the student in understanding the results of the successive differentiation of the vector $r\underline{r}_1$ in the lower half of the figure.

Figure 5 shows a rigid body with general motion in space. Successive differ-

Fig. 3



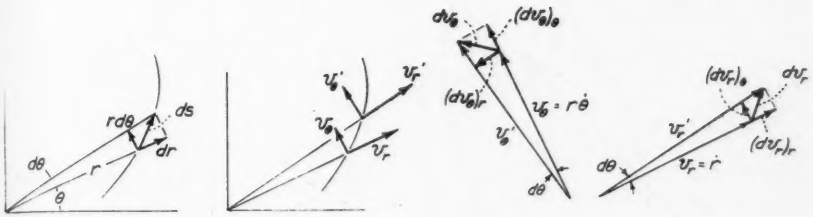
$$d\underline{S} = d\underline{r} = d\underline{\rho} = d\underline{\theta} \times \underline{r}$$
$$= d\underline{\theta} \times (\underline{\rho} - \underline{b})$$
$$= d\underline{\theta} \times \underline{\rho}$$
$$\underline{v} = \dot{\underline{r}} = \dot{\underline{\rho}} = \underline{\omega} \times \underline{\rho} = \underline{\omega} \times \underline{r}$$
$$\underline{a} = \dot{\underline{v}} = \ddot{\underline{r}} = \ddot{\underline{\rho}} = \dot{\underline{\omega}} \times \underline{r} + \underline{\omega} \times \dot{\underline{r}}$$
$$= \dot{\underline{\omega}} \times \underline{r} + \underline{\omega} \times (\underline{\omega} \times \underline{r})$$
$$\underline{a} = r\ddot{\theta}\underline{t}_1 + r\dot{\theta}^2\underline{n}_1$$



$$dv_n = v\,d\theta$$
$$a_n = v\omega = r\omega^2 = v^2/r$$

$$dv_t = d(r\omega) = r\,d\omega$$
$$a_t = r\dot{\omega}$$

Fig. 4



$(dv_r)_r = d\dot{r}$ $\quad (dv_r)_\theta = \dot{r}\,d\theta$

$(dv_\theta)_r = r\dot{\theta}\,d\theta$ $\quad (dv_\theta)_\theta = d(r\dot{\theta}) = r\,d\dot{\theta} + \dot{\theta}\,dr$

$a_r = \ddot{r} - r\dot{\theta}^2$ $\quad a_\theta = r\ddot{\theta} + 2\dot{r}\dot{\theta}$

LET $\underline{r}_1 \perp \underline{\theta}_1$ BE UNIT VECTORS, r- $\perp$ θ-DIRECTIONS

RECALL $\dot{\underline{r}}_1 = \underline{\omega} \times \underline{r}_1 = \dot{\theta}\underline{\theta}_1$ $\perp$ $\dot{\underline{\theta}}_1 = \underline{\omega} \times \underline{\theta}_1 = -\dot{\theta}\underline{r}_1$

$\underline{r} = r\underline{r}_1$

$\dot{\underline{r}} = \dot{r}\underline{r}_1 + r\dot{\underline{r}}_1 = \dot{r}\underline{r}_1 + r\dot{\theta}\underline{\theta}_1$

$\ddot{\underline{r}} = \ddot{r}\underline{r}_1 + \dot{r}\dot{\underline{r}}_1 + \dot{r}\dot{\theta}\underline{\theta}_1 + r\ddot{\theta}\underline{\theta}_1 + r\dot{\theta}\dot{\underline{\theta}}_1$

$= \ddot{r}\underline{r}_1 + \dot{r}\dot{\theta}\underline{\theta}_1 + \dot{r}\dot{\theta}\underline{\theta}_1 + r\ddot{\theta}\underline{\theta}_1 - r\dot{\theta}^2\underline{r}_1$

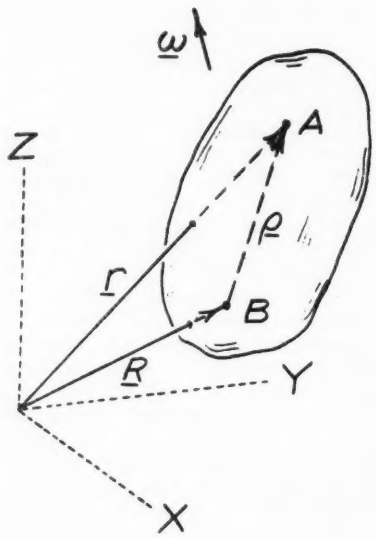
$= (\ddot{r} - r\dot{\theta}^2)\underline{r}_1 + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\underline{\theta}_1$

entiation of the vector triangle of position vectors yields immediately the relative velocity and acceleration equations in space. The step $\dot{\underline{\rho}} = \underline{\omega} \times \underline{\rho}$ is obtained by either of the two methods shown in the lower portion of the figure. The geometric approach is shorter and more descriptive physically than the more formal dependence on symbols and is an example of how geometrical meaning can be used to help establish the vector notation.

Figure 6 shows an example of the relative simplicity of a three-dimensional vector solution facilitated by the vector formulation of Figure 5. Here the link *OA* is confined to rotate about the fixed Z-axis through *O*. The link *BC* also rotates about the Z-axis, but *C* may slide along the axis. The joining link *AB* is provided with ball-and-socket hinges at *A* and *B*. A variety of nonlinear oscillations may be imparted to *C* depending on the relative frequency and phase relation between *OA* and *CB*. The figure shows the solution for the acceleration of *C* under the special symmetric conditions imposed. The inherent difficulty of a three-dimensional solution to the four-bar space linkage is easily handled for the special conditions shown.

Many other examples may be presented to illustrate the cautions, comparisons, and advantages of vector nota-

Fig. 5

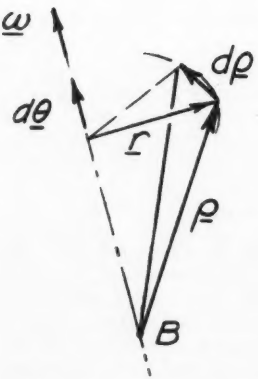


$$\underline{r} = \underline{R} + \underline{\rho}$$
$$\dot{\underline{r}} = \dot{\underline{R}} + \dot{\underline{\rho}}$$
$$\dot{\underline{r}} = \dot{\underline{R}} + \underline{\omega} \times \underline{\rho}$$

$$\ddot{\underline{r}} = \ddot{\underline{R}} + \dot{\underline{\omega}} \times \underline{\rho} + \underline{\omega} \times (\underline{\omega} \times \underline{\rho})$$

ATTACH x,y,z TO BODY, ORIGIN AT B

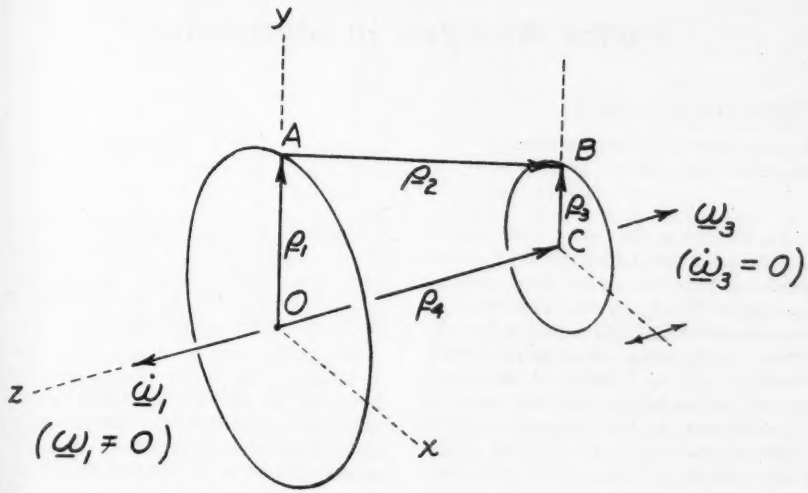
$$\underline{\rho} = \underline{i}x + \underline{j}y + \underline{k}z$$
$$\dot{\underline{\rho}} = \underline{i}\dot{x} + \underline{j}\dot{y} + \underline{k}\dot{z}$$
$$= \underline{\omega} \times \underline{i}x + \underline{\omega} \times \underline{j}y + \underline{\omega} \times \underline{k}z$$
$$= \underline{\omega} \times (\underline{i}x + \underline{j}y + \underline{k}z)$$
$$\dot{\underline{\rho}} = \underline{\omega} \times \underline{\rho}$$



$$d\underline{\rho} = d\underline{\theta} \times \underline{r}$$
$$= d\underline{\theta} \times \underline{\rho}$$
$$\dot{\underline{\rho}} = \underline{\omega} \times \underline{\rho}$$

tion for basic mechanics instruction. As instructors gain experience in presenting mechanics with the aid of Gibbs' notation, it is hoped that there will evolve an emphasis and technique which will accelerate the progress of students. In this process, instructors must undertake a constant and critical examination of the effectiveness of their presentations by thorough evaluation of the basic understanding acquired by their students. Facility for manipulative skill in analysis should not take precedence over the development of capacity to construct good mathematical models. Comparisons of tools of solution are also essential, for knowing when to use a tool is just as important as knowing how to use it. Lastly, we should not forget that our major obligation lies with the vast majority of our successful students, say the upper 50 per cent, and not merely with the top 1 or 2 per cent who should be given special challenges. The major burden of engineering accomplishment in the years immediately ahead will rest with this large group. We owe this group a maximum of clarity and insight with the engineering realities of mechanics. The use of vector notation should be developed with this objective in mind.

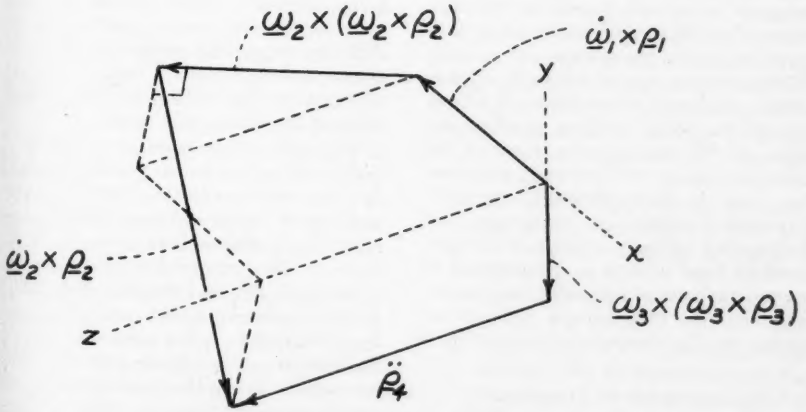
Fig. 6



$$\underline{a}_B = \underline{a}_B$$

$$\underline{a}_A + \underline{a}_{B/A} = \underline{a}_C + \underline{a}_{B/C}$$

$$\dot{\underline{\omega}}_1 \times \underline{\rho}_1 + \underline{\omega}_2 \times (\underline{\omega}_2 \times \underline{\rho}_2) + \dot{\underline{\omega}}_2 \times \underline{\rho}_2 = \ddot{\underline{\rho}}_4 + \underline{\omega}_3 \times (\underline{\omega}_3 \times \underline{\rho}_3)$$



Vector Analysis in Mechanics

FERDINAND L. SINGER

Professor of Mechanical Engineering,
New York University

To introduce the topic, we should specify our frame of reference. This depends on how we answer the following questions: What are the objectives of mechanics courses? Do they vary for different engineering disciplines? How should they be modified for students taking an undergraduate terminal program as contrasted to students contemplating graduate study? How can we best attain these objectives? What type of mechanics are we considering—engineering, classical or theoretical mechanics? Because each of us may have a different answer to these questions, many different texts are written; indeed, we may write one ourselves if we cannot find one to fit our objective.

My own credo is that mechanics correlates the disciplines of physics and mathematics by developing the ability to solve a wide variety of applications by means of a few basic principles. We must ensure that the student is adequately prepared to apply these concepts to such subsequent courses as strength of materials, mechanics of machinery, fluid mechanics, structural analysis, machine design, etc. We must also be aware of the changing requirements of other engineering curricula. Our colleagues, especially in electrical engineering, aeronautics, and engineering science, require that their students have at least an introduction to vector analysis and possibly also tensor notation, else their course work is retarded by the necessity of presenting it themselves. It seems apparent that mechanics is the ideal place in which to start using these tools. But the question is to what extent should they be used in the basic course in mechanics.

During the past two years I have experimented with vector analysis and find it particularly well suited to develop concisely and rigorously the general principles of mechanics, especially space mechanics. To do so, the student needs only to understand and be able to apply the notions of the dot product, the cross product and the derivative of a vector. These are relatively easy to learn and all students can benefit by learning that vector analysis is not as esoteric as it seems, and also to follow, intelligently, professional papers that may use this notation. At the appropriate place, tensor notation can also be used to great advantage. Indeed, to quote the author of a recent book, his students found it relatively easy to master tensor notation but had great difficulty in solving simple problems in statics and dynamics. I believe the explanation is that there was insufficient training in scalar techniques.

This author has, perhaps unwittingly, put his finger on the crux of the matter. It is not sufficient to teach a student the concepts of vector or tensor analysis—we must also teach him how to use them effectively. The principles of mechanics are surprisingly few and simple; what is difficult is to develop skill in applying these few principles to solve a wide variety of applications. And I mean *solve* to a numerical result; not the mere setting up of equations or of an analysis. If it has been difficult to attain this objective by scalar methods, it may be even more so using only vector methods wherein the mathe-

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matical manipulation of dot and cross products bears little resemblance to physical significance.

I have no reservations about using vector analysis provided we emphasize "analysis," but I do strongly object to overemphasizing its manipulative technique. I am particularly annoyed by advertising blurbs boasting about "a full vector treatment." There is an increasing trend to concentrate on three-dimensional mechanics and to ignore two-dimensional cases as trivial. Instead, I believe it trivial, and possibly foolish, to use the following "full vector treatment" to determine the reaction of a beam, viz.

$$Li \times Rj + ai \times (-Pj) = 0$$

when $RL = Pa$ expresses the physical concept of moment balance more concisely and significantly. This can only retard rather than enhance understanding of mechanics.

For the majority of engineers, plane mechanics constitutes about 90 per cent of their professional interest. To solve these coplanar problems requires skill in applying the scalar components of vector equations. It should be noted that these scalar equations need only to be multiplied by **i**, **j**, or **k** to be elevated to the dignity of vector equations. It is still important that our students recognize which group of scalar equations to use and in what combinations to apply them. Drill is needed on setting up and using free-body diagrams. Other important scalar techniques are the use of the sine law for solving force polygons of three forces in equilibrium, rotation of reference axes when there are more than three forces in equilibrium, selection of moment centers to eliminate unknowns, method of slopes in analyzing trusses, and use of the angle of friction.

In my opinion, it is unfortunate that most recent books in mechanics have overlooked these scalar methods. Coincident with the space age, these books have placed a major emphasis on space mechanics. Excellent discussions are presented on the concepts of motion relative to moving coordinate systems, trajectories of satellites and ballistic missiles, and rigid body motion about a point or its unconstrained motion in space. To do this effectively, it is only natural to use vector analysis. Vector analysis is also used very effectively to discuss the kinematics of plane motion, especially Coriolis' acceleration and radial and transverse components of acceleration. Without necessarily concentrating on space mechanics, I believe our students should be versed in applying vector analysis to these two-dimensional cases, not only for the conciseness and rigor of the presentation but also to satisfy the needs of our colleagues in other areas. However, we should not overlook another tool that is excellent for this purpose, namely, complex rectangular and polar notation.

There is a real danger that in the enthusiasm of using vector analysis, it may be overdone by the "full treatment." Actually, there is no advantage in using vector analysis for two-dimensional cases except where we are concerned with the rate of change of the direction of a vector, as in dynamics. However, for three-dimensional cases, vector methods provide both a more concise development as well as permit operations that are unwieldy with scalars, e.g., the moment of a force about *any* line. I would urge its adoption, therefore, as a tool to develop principles while retaining adequate drill in scalar techniques. Indeed, time may be saved and applications broadened by using vector analysis, but the order of presentation must be modified. As a suggestion, the order of topics in statics might be:

1. Vector algebra and vector products.
2. Complex rectangular and polar notation.
3. Numerical techniques for determining the components of a force and of its moment about a point or about any axis.
4. Resultants and equilibrium of space systems of forces.
5. Application to coplanar problems emphasizing the reduction of vector equations to scalar equivalents and training in scalar techniques.

I should like to end with a quote from the preface of L. A. Pars' excellent book, *Introduction to Dynamics* (Cambridge

University Press), because it seems so appropriate to the discussion. It reads:

"The vexed question of vectors, or rather of vector notation, has lately been much discussed, and the disputants have been seen maintaining with no little heat their various opinions . . . . One party stands for vector notation all the time—even for problems to which it is not particularly well adapted. In some expositions the whole emphasis seems to be on the manipulation of vector formulae rather than on dynamical principles, and we occasionally meet a proof that looks like a stunt or a conjuring trick. This party seems to regard the invention of Cartesian axes as a regrettable accident, a slightly indelicate matter seldom alluded to in polite society. The other party takes the diametrically opposite view. Its members seem always ill at ease with the vectors (just as writers a century ago were ill at ease with the complex variable) and they breathe a sigh of relief when they can get back—which they do as quickly as possible—to the friendly shelter of x, y and z . . . . In this book I have tried to avoid both these extremes . . . I have used vector notation freely when it substantially shortens or clarifies the argument. But I have not insisted upon it everywhere, because there will be some readers to whom it is unfamiliar, and these readers will make quicker progress if the unfamiliar notation is not used too freely . . . . A wide knowledge of the geometrical vector theory is not of comparable importance at this stage; it comes into its own in the field theories of electricity and hydrodynamics."

Vector Analysis in Mechanics

ARCHIE HIGDON

Colonel, USAF,
Professor & Head of Mechanics,
USAF Academy, Colorado

Not many years ago, perhaps even yet in a few situations, some people were still teaching courses in strength of materials without the use of the calculus. They did this primarily because their students in certain curricula, such as architecture, were not required to take calculus. Today the mathematical background and preparation of our students is far more advanced than utilized or required by most mechanics teachers. We talk of the immaturity of our students in mathematics, but we don't really mean it because we demand so little mathematics of them.

Today, we teachers of mechanics are faced with a great hue and cry to take advantage of vector methods in our teaching. Most of the quantities we use in our study of mechanics are vector quantities so it would seem somewhat natural to admit the obvious and use vector methods. However, we have been telling each other for 10, 20 or 30 years that our students don't understand vector methods and therefore we should be realistic and take all sorts of measures to avoid the use of vector algebra, much less vector calculus. Furthermore, after using scalar methods for 20 years or so, we have become rather adept in their use and are extremely reluctant to consider a change. We even say scalar methods are easier and I am sure they are for us after years of practice.

Fortunately our students haven't had all this practice with scalar methods and they appear to comprehend vector meth-

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ods as readily as scalar procedures. In fact, on the very limited trial run we made this year, it is just possible that the vector course produced more learning than our scalar course, even though we are definitely far more experienced teachers of the scalar methods.

Even if we insist on avoiding a change to vector methods until the bitter end, we won't have long to resist. Such leading texts as *Modern University Physics* by Richards, Sears, Wehr and Zemansky in physics and *Calculus with Analytic Geometry* by Taylor in mathematics now use vector terminology and Taylor contains a chapter on vector methods. When mathematics and physics courses include vector methods, how can we possibly ignore their use any longer?

Now don't get me wrong! I am making a plea for the use of vector analysis as a tool in exactly the same manner as calculus, trigonometry, the slide rule, etc. I do not advocate or even condone those who seek to use mechanics as an excuse to teach vector analysis instead of mechanics on mechanics time. We have all we can do to teach the necessary mechanics in the time allotted at most schools. I propose to use vector analysis as a tool to help me teach mechanics and to use it when it helps and not exclusively. However, I believe that vector methods must be used on simple problems to prepare for their use on more complex problems. In many cases vector terminology provides a more concise form for mechanics than we now use. The derivations in kinematics are more direct and easier to follow and problems not readily solved by scalar methods can be quickly formulated by vector methods even if the detailed solution does involve as much work as scalar procedures. For the student, the formulation or statement of the necessary equations is frequently very troublesome. As I see it, vector methods lead directly to a simple statement of the solution for many problems that require a lot of thought from the student with scalar methods.

I have been unable to find any proof of the common statement that vector methods obscure the physical meaning for the student. However, we intend to try out the vector approach this fall on a hundred students (seven sections) to see what more we can learn for and against vector procedures.

Professor Henry F. Hrubecky in the Mechanics Division Bulletin (pp. 763-4, JOURNAL OF ENGINEERING EDUCATION, May 1961), gives several excellent examples of the advantages of vector analysis in mechanics. In particular, he points out the fact that vector operations clarify the basic definitions, concepts, and analysis for the student. He further says that the relatively short time needed to present the vector fundamentals allows for greater course coverage instead of less coverage. I assume this statement means that he has found time to teach vector methods and mechanics even though the mathematics department has not already presented all necessary vector analysis.

COMPUTER CENTER AT ARLINGTON STATE

Arlington State College this summer dedicated a data computing center designed to strengthen the school's instructional programs in engineering and basic sciences as well as to insure the college a front-ranking position in college-based research in the North Texas area.

The center, built around a newly-installed IBM 1620 computer, will serve in a basic program of undergraduate instruction.

Dr. Wendell H. Nedderman, Dean of Arlington State's School of Engineering, emphasized that the school will not initially offer intensive training in computer programming techniques. The emphasis, he said, will continue to be on basic courses of study.

Teaching Undergraduate Mechanics by the Index Notation of Tensor Calculus

DANIEL FREDERICK

Professor of Engineering Mechanics, Virginia Polytechnic Institute

D. H. PLETTA

Head, Engineering Mechanics Department, Virginia Polytechnic Institute, Blacksburg, Virginia

During the past three decades and especially since the last war, there has been a marked trend to optimize designs so that the prototypes operate at very nearly their ultimate capacities. It has also become important for all engineers to understand and apply three-dimensional solutions to problems in dynamics, fluid mechanics, elasticity, etc. Such studies necessarily involve a three-dimensional spatial treatment and, for time dependent phenomena, the additional variable of time as well.

In the past ten years, we have observed a growing trend toward the use of vectors in undergraduate mechanics courses in order to facilitate these three-dimensional studies. Prior to this time, undergraduate mechanics was taught primarily on a two-dimensional basis and there was no need for true vector treatments. With the use of vectors, arguments on the pros and cons of teaching mechanics by vector calculus have arisen. These arguments raise questions regarding the best way of teaching three-dimensional mechanics. Is it by the use of vectors? One answer to these questions is that we should use the index notation of tensor calculus. Although it appears that this treatment is a move to an even higher mathematical level, this notation is a direct extension of the old two-dimensional scalar treatments. Students, therefore, should not have any additional trouble understanding abstract operations such as the cross and dot products, etc. which they encounter in classical vector treatments.

It is also becoming increasingly important for engineers to be able to understand tensor notation in order to read the literature and apply the results of this research to their own designs. Hence students must begin to use these newer notations so as to prepare for practice on a high professional plane, or graduate work, or both.

Up to now, the present vector analysis has proven rather popular in handling three-dimensional time-dependent mathematical formulations mainly because it was much more concise than the manipulations in scalar form. As one probes deeper into the more complex problems in engineering analysis, one soon finds that vectors are insufficient and that tensors as well as a knowledge of matrix algebra must be mastered. The cross and dot product and calculus of vectors are important tools but these and certain other vector operations such as dyads are considerably more cumbersome to manipulate than their counterparts in tensors. In fact, dyads are no longer popular in engineering literature. On the other hand the index notation involved in tensors applies equally well to scalars (tensors of zero order), vectors (tensors of the first order), and certain two-dimensional matrices (tensors of the second order) and also to quantities of any order higher than two. It also leads to a generalization of space (higher than

Presented at the Meeting of the Southeastern Section of the ASEE Engineering Mechanics Division, April 20-21, 1961, University of Mississippi, Oxford, Miss. Recommended for publication by the Mechanics Division of ASEE.

three) which is useful in many applied problems.

It would appear, therefore, that since the index notation can handle all phases of the mathematical manipulations of scalars, vectors, matrices, or tensors it would be much more appropriate to begin using it and actually discard the less efficient vector notation.

At the moment we shall probably have to continue to teach students to understand both vector notation and that part of tensors having to do with index notation. It might be safe to predict that in time the more powerful part of tensor analysis, that of index notation, will entirely supplant the classical notation of the cross product, dot product, the del operator, etc. currently being used in vector analysis today.

Engineering mechanics must of necessity deal with vectors. Until recently its presentation was restricted to scalar mathematics but vector notation has gained favor in the past few years. It would appear now that the treatment of vector algebra and calculus in index notation would be the most conservative approach, since it alone is progressively useful in tensor applications.

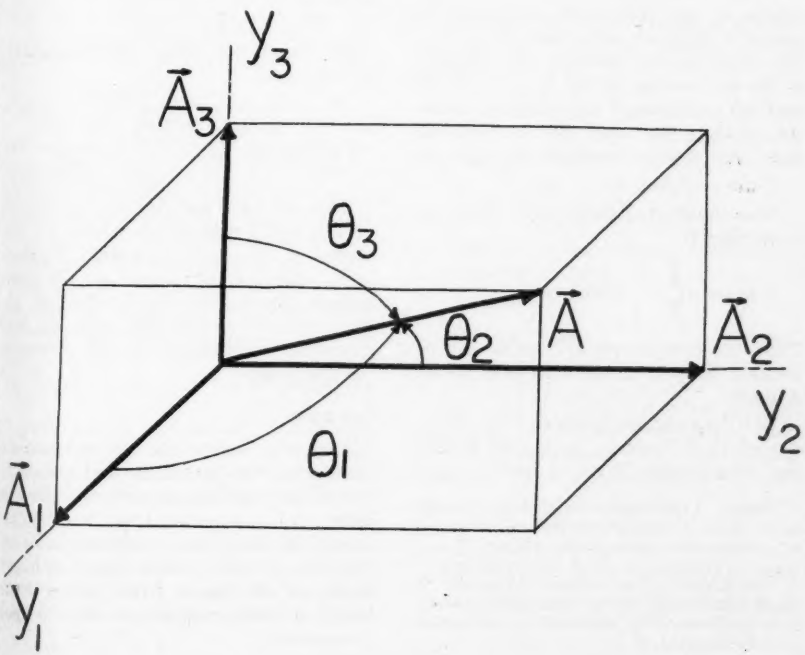
Vectors and Vector Components

(1) *Range and Summation Conventions.* To indicate the conciseness and clarity which arises from the tensor notation, some well-known definitions and equations will be presented.

Let y_1, y_2, y_3 be rectangular cartesian coordinate axes and let A be a vector located at the origin. It is well known that this vector can be resolved into three vector components $\mathbf{A}_1$, $\mathbf{A}_2$, and $\mathbf{A}_3$ along the axes. Or introducing unit vectors $\mathbf{i}_1$, $\mathbf{i}_2$, $\mathbf{i}_3$ these components can be written

$$\mathbf{A}_1 = A_1\mathbf{i}_1$$
$$\mathbf{A}_2 = A_2\mathbf{i}_2$$
$$\mathbf{A}_3 = A_3\mathbf{i}_3$$

where A_1, A_2, A_3 are the scalar magnitudes. At this point, using the index notation, we may introduce the *range*



convention[1] and refer to the vector by the magnitudes of its components, A_i.

A_i means the set $\{ A_1, A_2, A_3 \}$

Thus referring to the vector by A_i is equivalent to or better than the notation **A**, for given the set of numbers A_i and the coordinate system, the magnitude and direction of the vector can be found in the usual way. Its magnitude A, is given by

$$A^2 = (A_1)^2 + (A_2)^2 + (A_3)^3$$

or by the *summation convention*:[2]

$$A^2 = A_iA_i = A_1A_1 + A_2A_2 + A_3A_3$$

Thus the two important laws of the new notation; i.e. that of the range and of the summation notation, have been introduced almost painlessly.

(2) *Scalar or Dot Product.* Consider two vectors with components A_i and B_i. The dot product of these is by definition

$$A_iB_i = A_1B_1 + A_2B_2 + A_3B_3$$

The dot product of **A** with each of the unit vectors $\mathbf{i}_i$, yields the scalars

$$A_i = A \cos \theta_i$$

where θ_i are the angles between the vector **A** and each of the coordinate axes. The most familiar example in mechanics is the dot product of the force vector F_i and the infinitesimal displacement vector du_i yielding the work dw done by the force over the displacement du_i

$$dw = F_i du_i$$

Now integrating along some curve the work done is

$$w = \int_A^B F_i du_i$$

Thus, the components of a vector can be treated without introducing the vector **A** itself.

(3) *Permutation Symbols, Cross Product of Two Vectors.* As is well known the cross product is not as easy to teach and understand. To introduce the cross product in the new notation it is necessary to introduce permutation symbols.

By definition, the permutation symbols are ε_{ijk}, where

$\varepsilon_{ijk} = 0$ if any two suffixes are alike.

$= +1$ if the suffixes (i, j, k) are an even number of permutations of the numbers (1, 2, 3).

$= -1$ if the suffixes (i, j, k) are an odd number of permutations of the numbers (1, 2, 3).

Thus the six non-zero components are

$$\varepsilon_{123} = \varepsilon_{231} = \varepsilon_{312} = +1$$
$$\varepsilon_{321} = \varepsilon_{213} = \varepsilon_{132} = -1$$

which are easy to remember since the plus one and minus one elements are obtained by cycling the numbers (1, 2, 3) and (3, 2, 1) respectively.

With these permutation symbols the cross product of the displacement vector ρ_i with the force vector F_i yields the moment vector M_i

$$M_i = \varepsilon_{ijk}\rho_j F_k$$

Or, using the range and summation conventions

$$M_1 = \varepsilon_{ijk}\rho_j F_k = \varepsilon_{123}\rho_2 F_3 + \varepsilon_{132}\rho_3 F_2$$
$$= \rho_2 F_3 - \rho_3 F_2$$

Similarly $M_2 = \rho_3 F_1 - \rho_1 F_3$

$M_3 = \rho_1 F_2 - \rho_2 F_1$

Thus we have avoided the use of unit vectors and determinants which are employed in the classical notation. Furthermore, attention is focused on the components themselves which after all are the quantities sought. The physical and geometric interpretations are obviously the usual ones.

Examples

Presented below for the purpose of illustrating the simplicity and compactness of the notation are some well-known laws and equations from mechanics. These are given here without proofs or preliminary developments which in many instances are almost trivial when compared with the methods of classical vector analysis.

[1] Range Convention—Whenever a small Latin suffix occurs unrepeated in a term, it is understood to take on the values 1, 2, and 3 and to represent a set of three elements.

[2] Summation Convention—Whenever a small Latin suffix occurs repeated in a term, it is understood to represent a summation over the range 1, 2, 3.

(1) *Associative Law for Addition of Vectors.*

$$A_i + (B_i + C_i) = (A_i + B_i) + C_i$$

(2) *Moment of a Force F_i, about a point.*

$$M_i = \varepsilon_{ijk}\rho_j F_k$$

where ρ_j is the positive vector,

(3) *Equilibrium Equations of Statics.*

$$\Sigma F_i = 0 \qquad \Sigma M_i = 0$$

which are the familiar "sum of the forces along the three axes" and "sum of the moments about the three axes" equal to zero.

(4) *Equilibrium Equations in Continuum Mechanics.*

This example provides an opportunity to introduce another shorthand notation; that of representing the partial derivative of a function $\mathbf{F}\ (y_1, y_2, y_3)$ with respect to a position coordinate by a comma. Thus

$F_{,i}$ represents the set

$$\left\{ \frac{\theta F}{\theta y_1}, \frac{\partial F}{\partial y_2}, \frac{\partial F}{\partial y_3} \right\}$$

which is another way of saying that the grad F can be written as $F_{,i}$. Similarly, the div $\mathbf{F} = F_{i,i}$ and the curl F has the same meaning as $\varepsilon_{ijk}F_{k,j}$.

The power of this notation is even more apparent when one considers the equilibrium equations for a continuous medium. Here, the nine components of stress may be expressed as σ_{ij}. Actually, of course, only six are independent, for the six shear components pair off so that $\sigma_{23} = \sigma_{32}$, etc. When one sums the forces, not stresses, which act on an elemental volume, the variations in σ_{ij}, such as

$$\frac{\partial \sigma_{11}}{\partial y_1}\delta y_1 \text{ etc.,}$$

due to the inhomogeniety of the state of stress, and the surface areas of the volume appear. The equilibrium equation applicable in the y_1 direction for forces thus takes the form of

$$\frac{\partial \sigma_{11}}{\partial y_1} + \frac{\partial \sigma_{12}}{\partial y_2} + \frac{\partial \sigma_{13}}{\partial y_3} + X_1 = 0$$

In index notation, where X_i are body forces, all three equations become

$$\sigma_{ij,j} + X_i = 0$$

(5) *Differentiation of a Vector with Respect to Time.*

Let $\mathbf{F}(t)$ or $F_i(t)$ be a vector that varies in magnitude and direction. The formal definition of the derivative is then

$$\frac{dF_i}{dt} = \underset{\Delta t \to 0}{\text{Limit}} \frac{F_i(t + \Delta t) - F_i(t)}{\Delta t}$$

If $A_i(t)$ and $B_i(t)$ are two vectors, then some well-known laws for differentiation are

$$\frac{d(A_i + B_i)}{dt} = \frac{dA_i}{dt} + \frac{dB_i}{dt}$$

$$\frac{d(A_iB_i)}{dt} = A_i\frac{dB_i}{dt} + \frac{dA_i}{dt}B_i$$

$$\frac{d}{dt}(\varepsilon_{ijk}A_jB_k) = \varepsilon_{ijk}A_j\frac{dB_k}{dt} + \varepsilon_{ijk}\frac{dA_j}{dt}B_k$$

In the last identity, the permutation symbols are constants and have been treated as such in the differentiation.

Let ρ_i be the position vector of a moving particle. Then the velocity of the particle is

$$v_i = \frac{d\rho_i}{dt}$$

and the acceleration is

$$a_i = \frac{dv_i}{dt} = \frac{d^2\rho_i}{dt^2}$$

or using a dot to indicate a derivative with respect to time

$$v_i = \dot{\rho}_i$$

$$a_i = \dot{v}_i = \ddot{\rho}_i$$

(6) *Transformation Equations.*

In all fields of mechanics the transformation of the laws and quantities from one set of coordinates to another is often necessary. These calculations are usually time consuming and lengthy. The tensor notation lends itself naturally to this problem for the basic idea in tensor analysis involves transformations from one set of coordinates to another. When written in true tensor form, all laws and equations hold for any coordinate systems.

Let y_i and y'_1 be two sets of rectangular coordinate axes and let a_{ij} be the direction cosines between them. These direction cosines may be arranged as shown below.

	y'_1	y'_2	y'_3
y_1	a_{11}	a_{12}	a_{13}
y_2	a_{21}	a_{22}	a_{23}
y_3	a_{31}	a_{32}	a_{33}

For example a_{13} is the cosine of the angle between the y_1 and y'_3 axes.

The ease with which one can transform the components of a vector (first ordered tensor) from say an unprimed to a primed coordinate system is apparent from an expansion of the following relationship. Let M_i and M'_i be components of a vector in the y_i and y'_i coordinate systems. Then

$$M_i = a_{ji}M'_j$$

where $M_1 = a_{11}M'_1 + a_{21}M'_2 + a_{31}M'_3$, etc.

Similarly, a transformation from a primed to an unprimed system is given by

$$M'_i = a_{ij}M_j$$
$$M'_1 = a_{11}M_1 + a_{12}M_2 + a_{13}M_3.$$

Transformation equations for second-ordered tensors such as the inertia tensor I_{ij} and the stress tensor σ_{ij}, can be written as follows.

$$I_{ij} = a_{ir}a_{js}I'_{rs}$$
$$\sigma_{ij} = a_{ir}a_{js}\sigma'_{rs}$$

Note that these hold only for transformations between sets of coordinates which are rectangular cartesian and do not hold for transformations involving general coordinates.

Summary

The salient features of the index notation have been presented here and the advantages it offers over the classical vector and matrix notation were pointed out. The important advantages might be summarized as follows:

(1) The three-dimensional (or N-dimensional) case is just as easy to handle as the two-dimensional one.

(2) The notation focuses attention on the components directly. They are not hidden as in the vector or matrix notation.

(3) It prepares a student for further study on a graduate or post-professional level where the concepts of invariance and N-dimensionality are important.

(4) A compactness in writing and presentation is achieved which leads to increased understanding.

(5) Proofs for vector identities (some quite involved otherwise) containing dot and cross products, div., curl, grad., etc. are almost trivial in the index notation.

On the negative side, one might wonder whether a term containing two cross products is easier to handle in the new notation since it would contain two permutation symbols. By expanding each symbol and using its definition these expressions lead to some simple identities. Therefore, these cross products are as easy or easier to manipulate than with the usual vector notations.

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I. H. Shames, *Engineering Mechanics, Statics and Dynamics*, McGraw-Hill (1960).

PETERS DEAN AT COLORADO

Dr. Max S. Peters, 41, head of the division of chemical engineering at the University of Illinois, has been named dean of the College of Engineering at the University of Colorado. He succeeds Dean Emeritus Clarence L. Eckel, who retired in 1960 after 46 years on the U. of C. faculty.

RONALD *books for engineers . . .*

LINES, WAVES, and ANTENNAS

The Transmission of Electric Energy

ROBERT GROVER BROWN, Iowa State University;
ROBERT A. SHARPE, Iowa State University; and
WILLIAM LEWIS HUGHES, Oklahoma State University

A carefully integrated introduction to the principles of electric energy propagation. Pulse transmission along lossless lines is treated first in order to establish clearly the basic ideas of propagation and reflection. Transmission-line phenomena are further developed from the circuit theory viewpoint with the study of the sinusoidal case. Transmission-line analogy is used whenever possible in discussing electromagnetic wave theory. *Instructor's Manual available. 1961. 297 pp., illus.* **$10**

HIGHWAY ENGINEERING

LEO J. RITTER, Jr., Associate Editor, "Engineering News-Record";
and **RADNOR J. PAQUETTE**, Georgia Institute of Technology

Second Edition offers co-ordinated coverage of all phases of highway engineering. Logically organized book examines major factors in the order in which they would be encountered in the development of a highway or highway system. In addition to practical material on the preparation of plans and contracts, facts on modern equipment, and construction and maintenance details, book fully covers the administration, economics, financing, and over-all planning of a modern highway. *"The exceptional text in the field today."*—**Neilon J. Rowan,** *Agricultural and Mechanical College of Texas. 2nd Ed., 1960. 751 pp., illus.* **$10**

STATICALLY INDETERMINATE STRUCTURAL ANALYSIS

R. L. SANKS, Gonzaga University

This new book offers a thorough treatment of three independent analysis methods in wide use: moment area, virtual work, and moment distribution; plus a concise presentation of other methods. It stresses understanding the theory, observing the interrelation of the several methods, and use of worthwhile computional shortcuts. The concept of cut-back structures is employed effectively for deflection calculations; the use of elastic checks is developed in detail. Nearly 550 problems, illustrated with hundreds of line drawings are included. The Instructor's Manual provides complete solutions to typical problems. *1961. 602 pp., illus.* **$10**

THE DYNAMICS and THERMODYNAMICS of COMPRESSIBLE FLUID FLOW

Parts I and II from Volume I

ASCHER H. SHAPIRO, Massachusetts Institute of Technology

Parts I and II (chs. 1 to 8) **of this definitive work bound separately. Ideally suited for the short undergraduate course, this textbook provides a thorough introduction to compressible fluid mechanics. Part 1 clearly explains the basic principles and concepts of fluid dynamics and thermodynamics, and the introductory concepts of fluid flow. Part II carefully examines the fundamental principles of one-dimensional flow. Tables of compressible-flow functions are appended.** *"A consistent, integrated, and fundamental approach . . . clear and readily understood by students."*—**S. J. Kline,** *Stanford University. 1958. 293 pp., illus.* **$8.50**

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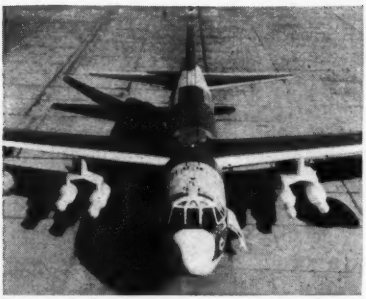
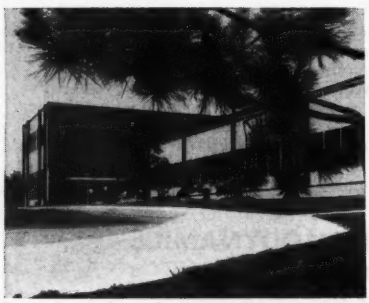


Military aircraft



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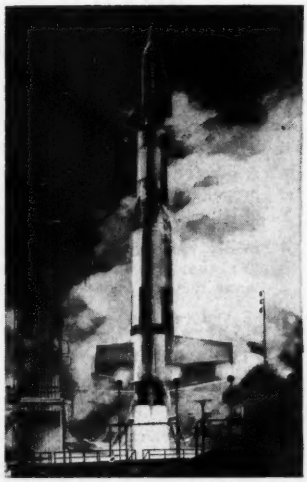

Missiles and space vehicles

CAREER BULLETIN FROM BOEING

The wide variety and the continuing growth of such Boeing programs as those illustrated on this page offer outstanding career openings to graduates in engineering, scientific and management disciplines. At Boeing your students will enjoy the advantages of a professional climate that is conducive to deeply rewarding achievement and rapid advancement. Other Boeing advantages include up-to-the-minute facilities, a dynamic industry environment and company-paid graduate study programs (Masters and Ph.D.).

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14th Annual College-Industry Conference

Engineering Education for International Competition

Relations With Industry Division of ASEE

Worcester Polytechnic Institute

February 1-2, 1962

This conference is a forum where industrialists and educators can discuss their mutual problems in the production and utilization of engineering talent. This year the speakers, drawn from both industry and education, will explore the needs of industry to compete with foreign production and the corresponding educational requirements of the undergraduate curriculum. The problems of continued education after graduation, in both on- and off-campus programs, will also be discussed.

PROGRAM

Thursday, February 1st

9:30 "The Educational Needs of Industry"
Presiding: Burton C. Baker, Chairman, RWI-ASEE
Welcome: Arthur B. Bronwell, President, WPI

9:45 Keynote Address: J. Herbert Hollomon, General Manager of General Eng. Laboratory, General Electric Co.

10:45 "Needs in Design and Advanced Engineering"
Lester V. Colwell, Prof. of Mech. Eng., Univ. of Mich.

11:15 "Needs in Production and Applications"
Joseph R. Carter, General Manager Eastern Division, Wyman-Gordon Co., Worcester, Mass.

11:45 Questions and discussion.
Moderator: Donald N. Zwiep, Head, Dept. of Mech. Eng., WPI

12:15 Luncheon. Presiding: Wayne E. Keith, New England Tel. & Tel. Co., Chairman, Industry Advisory Committee
Address: Martin Schilling, Engineering & Research, Raytheon Co., Lexington, Mass.

2:00 "Curricula to Meet the Needs"
Presiding: M. Lawrence Price, Dean of Faculty, WPI

2:15 "The Engineering Curriculum"
H. Guyford Stever, Prof. of Mech. Eng., Massachusetts Institute of Technology

2:45 "The Engineering Curriculum"
Ralph D. Bennett, Director, Research & Development, Martin Co., Baltimore, Maryland

3:15 "The Engineering Curriculum"
Walter R. Beam, Head, Dept. of Elect. Eng., Rensselaer Polytechnic Institute

3:45 Questions and discussion. Moderator: M. Lawrence Price

4:15 Adjourn afternoon session.

6:30 Social Hour

7:15 Banquet. Presiding: Arthur B. Bronwell, President, WPI
Address: Hilliard W. Paige, Manager, Missile and Space Vehicle Department, General Electric Co.

Friday Morning, February 2

9:30 "Industry Sponsored Programs"
Presiding: Glen A. Richardson, Head, Dept. of Elect. Eng., WPI

9:45 "On Campus Programs"
Robert I. Strough, Pratt & Whitney Div., United Aircraft, Hartford, Conn.

10:30 "A Motor Industry Program"
Harold P. Rodes, President, General Motors Institute

11:00 "An Educator's Viewpoint"
Peter Elias, Prof. of Elect. Eng., M.I.T.

11:30 Questions and discussion. Moderator: Glen A. Richardson

12:30 Luncheon. Presiding: B. Leighton Wellman, Prof. of Mech. Eng., WPI
President's Message: Robert W. Van Houten, President of Newark College of Engineering and of ASEE
Address: Earl P. Stevenson, Chairman of the Board, Arthur D. Little, Inc., Cambridge, Mass.

2:30 Adjournment

For a copy of the final program and registration forms write: RWI College-Industry Conference, Worcester Polytechnic Institute, Worcester 9, Mass.

What's Going on in ASEE

Society Activities Including the Major Actions of the Executive Board at their October Meeting

J. W. SEYLER
Asst. Secretary, ASEE

Reports from the four Section meetings held in October indicate that attendance is running unusually high this year. Good Section programs are primarily responsible for the good attendance at Section meetings. Reorganization of the Society is being discussed at all Section meetings.

Division activities are humming as usual. The Mineral Engineering Division is requesting a one-day session at the Colorado School of Mines in conjunction with the Annual Meeting in June, 1962. The Electrical Engineering Division's request for funds to print copies of a report, "Electrical-Mechanical Energy Conversion" has been approved. The Educational Methods Division proposal for a conference on Educational Models and Systems Engineering has been approved by the Projects Committee. Financial support for this conference is being sought. The Summer Institute on Effective Teaching, held the last two years at The Pennsylvania State University, is expected to continue in 1962. The Industrial Engineering Division has submitted a proposal on a Symposium to Develop a Guide Curriculum for Undergraduates Industrial Engineering Program in the United States. A proposal for a Study of Objective Criteria in Ceramic Engineering Education has been received and transmitted to the Projects Committee.

Requests have been received recently for permission to translate ASEE publications into Spanish and Japanese. The international interest in ASEE is being expressed more each day. The American Society for Engineering Education is having a direct effect on international engineering education as well as engineering education in the United States.

ASEE has been asked by Engineers' Council for Professional Development to undertake a new evaluation of engineering education. The Society has accepted the invitation. The Projects Committee will proceed immediately to submit a proposal for financial support and to select an appropriate committee.

Membership

The number of new individual membership applications received are running slightly above what the number was at this same time last year. This is due primarily to the activities of the membership chairmen on each campus. A survey last year revealed that on many campuses more than 50 per cent of the engineering faculty members were not members of ASEE. Local membership chairmen have accepted the responsibility of informing these people of the activities of ASEE and inviting them to join the Society. Since engineering education is the primary interest of engineers serving on an engineering faculty, it is important that they take an active interest in the continuing improvement of engineering education.

Divisional interest of members has been coded. Society headquarters can now provide Divisions, as well as Sections, a breakdown for the membership

of the Society. Address labels for members of any Division or Section may be obtained from the Secretary at no charge.

Additional industrial, associate, and affiliate memberships have been approved with 16 new affiliate members added during the first three months of this fiscal year.

Journal of Engineering Education

A book review section for the JOURNAL OF ENGINEERING EDUCATION has been approved. Reviews will be limited to books dealing with engineering education and will not include text books.

Special Projects and Proposals

All proposals from individuals, committees, divisions, etc., of the Society should be directed to the Projects Committee. This committee will review proposals and for those accepted will seek financial support if necessary. An outline for the procedure to be followed in submitting proposals may be obtained from the office of the Secretary.

New Committees and Appointments

The Engineering College Administrative Council has announced the appointment of two new committees. The Committee on the Analysis of Engineering Enrollments will have as its chairman L. A. Brothers. The committee to consider all matters germane to the young men in engineering teaching will have as its chairman D. V. Heebink.

The Engineering College Research Council announced a new Committee on Research in Graduate Study with J. C. Calhoun, Jr., as chairman. The committee will study the importance of research programs in graduate study.

President Van Houten announced the appointment of Dr. Alex Rathe as the ASEE representative to the newly-formed Industrial Engineering Terminology Committee of the American Society of Mechanical Engineers.

Two *ad hoc* committees have been appointed by President Van Houten. One Committee is to study the location of Society headquarters. C. C. Chambers is chairman. Members of the committee are J. C. Calhoun, Jr., E. C. Easton, John Gammell, F. C. Lindvall, R. A. Morgan, with W. Leighton Collins and R. W. Howes as consultants.

The other committee is to study the dues structure for members 36 years of age and under. B. J. Dasher is chairman. W. W. Burton, A. B. Cambel, H. A. Foecke, G. D. Lobingier, C. E. Schaffner and A. Ray Sims are members of the committee.

RADIATION PROTECTION PROGRAM AT NEVADA SOUTHERN

Formal college courses to train students in protection against radiation exposure are in the planning stage at the University of Nevada's southern regional division in Las Vegas.

Dr. William Carlson, dean of Nevada Southern, said courses are being developed which may even lead to baccalaureate degrees in radiation protection and control for those students who want to specialize as technicians in the field. An evaluation of the need for such technicians is now under way at Nevada Southern under an $18,500 grant from the federal government's radiological health division, which has a laboratory on the local campus.

According to estimates of the U. S. Surgeon General's national advisory committee on radiation in 1959, 4,000 technicians will be required by 1970 to meet the needs in industry, research, and federal, state, and local health agencies

The radiological laboratory on the Nevada Southern campus serves the area west of the Mississippi and is the only one to be found on a university or college campus. Expanding programs in radiation protection and control on a national, state and local level, are said to be hampered by a serious shortage of radiation technicians.

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Kansas-Nebraska	University of Nebraska	Oct. 1962	P. G. Kirmser, Kansas State University
Michigan	Wayne State Univ.	April 7, 1962	J. S. Johnson, Wayne State Univ.
Middle Atlantic	Columbia University	Dec. 1961	J. G. Truxal, Brooklyn Poly. Inst.
Missouri-Arkansas	Univ. of Arkansas	April, 1962	J. L. Imhoff, Univ. of Arkansas
National Capital Area			G. L. Hickox, Alexandria, Virginia
New England	Dartmouth College	Oct., 1962	H. R. Beatty, Wentworth Institute
North Midwest	North Dakota State University	Oct., 1962	F. C. Mirgain, North Dakota State Univ.
Ohio	Ohio University	April, 1962	L. F. Hicks, Ohio University
Pacific Northwest	Washington State University	April 27 & 28, 1962	L. D. Luck, Wash. State Univ.
Pacific Southwest	Las Vegas, Nevada	Dec. 27 & 28, 1961	A. C. Ingersoll, Univ. of Southern Calif.
Rocky Mountain	Univ. of Colorado	April 28, 1962	H. E. Johnson, III Univ. of Colorado
Southeastern	Vanderbilt University	April, 1962	L. E. Schoonmaker, Univ. of Florida
Southwest	Texas Tech. College	April 6 & 7, 1962	I. W. Roark, Univ. of Tulsa
Upper N. Y.-Ontario	Alfred University	Oct., 1962	F. H. Gertz, Alfred Univ.

Mid-Winter Meetings - 1962

Cooperative Education — Jan. 22-24, 1962 — Hotel Ambassador, Washington, D. C.
Information: M. J. Vaccaro, Goddard Space Flight Center, Greenbelt, Md.

Engineering Graphics — Jan. 16-18, 1962 — University of Wisconsin
Information: K. G. Shiels, Assistant Dean of Engineering, University of Wisconsin, Madison, Wisconsin.

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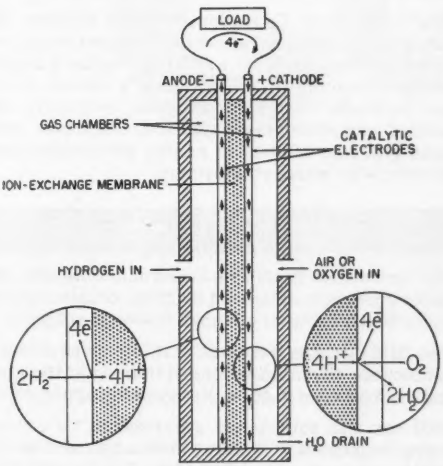

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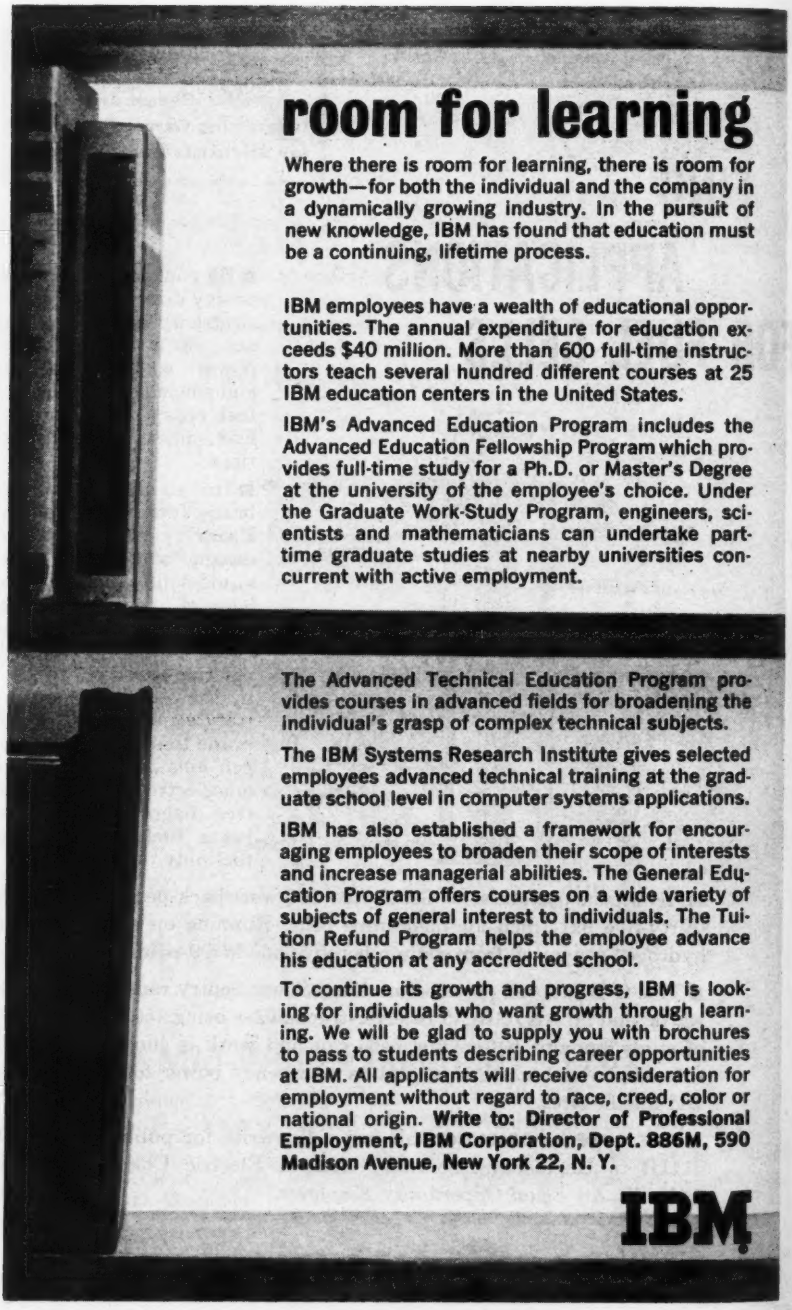

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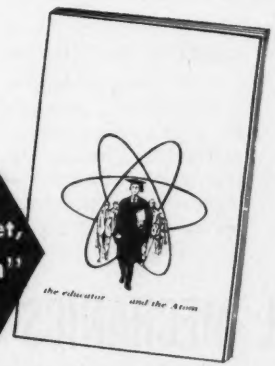

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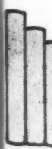

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